New England Water Works Association

ORGANIZED 1882.

Vol. L. March, 1936. No. 1.

This Association, as a body, is not responsible for the statements or opinions of any of its members

WATER SUPPLY PROBLEMS IN THE TROPICS OF SPANISH AMERICA.

BY GEORGE C. BUNKER.*

[*Read September 18, 1935.*]

Altitude, Latitude and Temperature. The tropics — that section of the earth's surface between the tropic of Cancer and the tropic of Capricorn which form the limits of the Torrid Zone — are generally thought of as having a low altitude, a climate uncomfortably hot and humid, and torrential rains. In reality the Torrid Zone contains a bagful of surprises relative to climate, altitude and miscellaneous phenomena. The climate of a country in the Torrid Zone is almost wholly determined by its altitude above sea level, although there may be local variations due to special topographical influences.

For example, in Ecuador, through which the equator passes, there are the lowlands, hot and comparatively dry along the Pacific coast, and also hot but extremely humid on the east side of the Andes mountains; above the lowlands in the mountainous area, there are regions with the characteristics of a temperate zone at elevations varying from 7 500 to 10 000 ft. above sea level; above this zone there are the cold, bleak plateaus at elevations from 10 000 to 15 000 ft.; and above the latter are the high peaks of the Andes mountains which run across the country from north to south. That portion of the Andes from about latitude 2 deg. south to the Colombian frontier is characterized by lofty, volcanic peaks of which the most important ones range in height from 14 038 to 20 696 ft. with several covered with perpetual snow and ice. Ecuador is reported to be more subject to volcanic disturbance than any other South American country.

Quito, the capital of Ecuador, situated practically on the equator, latitude 14 min. south, has an altitude of 9,343 ft. above sea level in the Plaza Mayor and an average annual temperature of 55°F. It occupies a small basin of the great central plateau. In contrast, the principal port of Ecuador, Guayaquil, while only 288 miles from Quito, at latitude 2 deg. 1 min. south and at nearly sea level, has a mean annual temperature of about 81.5°F.

*Consulting Engineer, Ancon, Canal Zone, Panama.

Colombia furnishes another example of climatic contrasts. This country extends from latitude 4 deg. 20 min. south to latitude 12 deg. 20 min. north, but the greater part of it lies in the northern Torrid Zone. In general, the lowlands, including the coastal planes and the valleys of the larger rivers, are hot. Above the lowlands, a cooler climate is found in the valleys and slopes lying between altitudes of 1 500 and 7 500 ft. above sea level, a region sometimes designated as the subtropical zone. Some of the districts in the latter are the most fertile and productive areas of the country. As in Ecuador, there is a temperate zone between altitudes of 7 500 and 10 000 ft. above sea level which changes to a cold, bleak zone between the latter elevation and one of 15 000 ft. On the high plateaus, known as *paramos*, at an altitude of 10 000 to 12 000 ft. above sea level, the temperature drops to about 23°F. during the nights in the rainy months, and frost forms on the ground. During the greater part of the rainy months, a thick mist hangs over the land which, with the low temperature, renders the *paramos* uninhabitable, but the picture is better painted by R. Cunninghame Graham:[1]

> These high desert plateaux, known as *paramos*, lie at an altitude of ten to twelve thousand feet, and are inhabited by a few miserable Indians, who cultivate enough potatoes to sustain existence, and possess some herds of goats. The winds are icy; magnetic storms of fearful violence break over them at frequent intervals, and but for the tall plant known to the inhabitants as *Frailejon* and a short wiry grass, the pastures of the goats are absolutely bare.

The central mountain range of Colombia has a series of lofty volcanic peaks, some of them snow-capped perpetually, the highest of which is reported as 18 432 ft. above sea level. In the northern end of the country, not far from the Atlantic port of Santa Marta, there is a ridge of mountains known as the Sierra Nevada de Santa Marta with snow-covered peaks. The highest of these mountains is reported to be 17 339 ft. above sea level.

Bogota, the capital of Colombia, at latitude 4 deg. 36 min. north, has a mean altitude of 8 672 ft. above sea level. Water boils at a temperature of approximately 198°F. During the years 1924 to 1933, inclusive, the ranges in temperature were as follows: minima, 39.7 to 43.0°F.; maxima, 72.5 to 75.2°F.; and mean, 56.8 to 58.6°F.

In contrast, the principal Pacific port, Buenaventura, while only 250 miles from the capital at latitude 3 deg. 54 min. north and at nearly sea level, has a mean annual temperature of about 80°F. Barranquilla and Cartagena, the two principal Atlantic ports, have a mean annual temperature of about 81.5°F.; cities located at an altitude of about 3 200 ft. above sea level have a relatively uniform mean annual temperature of about 73°F.; and cities at an elevation of about 4 800 ft. have a climate similar to perpetual spring with a mean annual temperature of about 68°F. The mean temperature of a city may be generally approximated by the rule that it decreases one degree Fahrenheit with every 330 ft. increase in elevation. A mean annual temperature of 81.6°F. is exceeded in very few sections of South America.

The Panama Canal Zone lies wholly within the Torrid Zone and very close to the thermal equator or the region of the earth inclosed within the annual isotherms of 80°F. Its climate may be characterized as warm, humid and equable. Average temperatures are remarkably uniform from month to month, and sudden changes seldom occur. The highest mean temperature occurs in April toward the end of the dry season and the lowest in November near the end of the rainy season.

During 27 years of record the temperature at Cristobal, close to Colon, has varied as follows: mean, 80.0; mean maximum, 85.3; absolute maximum, 95; mean minimum, 76.0; and absolute minimum, 66°F. During 29 years of record the temperature at Balboa Heights, close to Panama City, has varied as follows: mean, 78.7; mean maximum, 87.4; absolute maximum, 97; mean mimimum, 73; and absolute minimum, 63°F. A temperature of 100°F. has never been recorded during these periods.

Precipitation. No attempt will be made to discuss the rainfall in the tropics in detail, but some of the more prominent characteristics will be pointed out. Seasonal distribution is an important factor in the selection of a water supply and varies greatly.

The heaviest rainfall in South America[2] occurs in a narrow area along part of the Pacific Coast of Colombia and Ecuador which starts at a short distance north of the Gulf of Guayaquil. At Buenaventura, Colombia, the mean annual rainfall is about 280 inches; at Andagoya, about 90 miles northeast of Buenaventura at latitude 5 deg. 4 min. north, it is 279 in.; and at Buena Vista, about 25 miles north of Andagoya at latitude 5 deg. 30 min., it is about 331 in., more than at any other point on record in South America. The rainfall for 1928 at Andagoya, 340.85 in., was unusually high.

At Andagoya, the individual monthly totals, from 1914 to 1925, ranged from 8.55 to 47.83 in. The minimum rainfall at Andagoya and Buenaventura occurred during January, February and March and represented about 16 per cent of the annual total. At Andagoya nearly 80 per cent. of the precipitation fell between 7 P.M. and 7 A.M. The maximum rainfall during 24 hours was 8.11 in. From 1917 to 1925, inclusive, the mean annual temperature at Andagoya was 81.6°F.; a maximum of 100°F. was recorded on only four days; and the minimum was below 70°F. on only five days.

The statement has been made that it rains every day at Buenaventura, but this is not correct as there are usually from two to five days without rain during the months of greatest precipitation. Even in a region with such a high mean annual rainfall as occurs here one should consider the possibility of droughts in selecting a stream from which a water supply is to be taken. During the early part of 1929 there was an unusually long dry season with relatively little rainfall during a period of 80 days. The precipitation during January and February, 1931, was 6.88 in. and 5.24 in., respectively, as compared with 18.48 and 16.58 in. during the same months in 1930, and an average of about 26 in. during the months of greatest

precipitation. During January and February, 1931, there were 16 and 9 days, respectively, without rains.

There is a sharp drop in the rainfall from the Pacific coast to the elevated interior of Colombia, east of the western range of the Andes, as may be seen from the following table.

TABLE 1.— RAINFALL IN THE INTERIOR OF COLOMBIA.

City.	Elevation Above Sea Level — Feet.	Latitude North. Deg.	Min.	Distance from Pacific Coast in Direct Line. Miles.	Mean Annual Rainfall. Inches.
Cali.....	3 500	3	25	55	48
Medellin.....	4 950	6	10	120	58
Bogota.....	8 672	4	36	220	40

The coast of Colombia along the Caribbean Sea offers a sharp contrast to the Pacific coast in respect to precipitation. The mean annual rainfall varies from about 40 to 50 in. except in the Gulf of Uraba where it rises to 60 in. The heavier rains occur from June to November, especially during the latter three months. The minimum rainfall occurs during December, January and February and is generally less than 2 in.; at Cartagena, 0.4 in.

The Santa Marta region receives an annual mean rainfall not exceeding 18 in., but the precipitation is very erratic and in some years drops to 6 to 9 in. The banana plantations are irrigated by numerous streams from the mountains at the southeast.

The coast between Cartagena and Barranquilla is rather arid for a distance of about 30 miles inland, although some low areas are flooded during seasons of high water in the Magdalena River. The mean annual rainfall at Cartagena is about 36 in. There are frequent years of extreme drought lasting from October to May. Excessive rains and violent rains occur about every eighth year causing considerable damage.

The northern highlands of Ecuador, Colombia and Venezuela, and a large proportion of the plains, receive on the whole between 40 and 50 in. of rainfall annually, but many local differences occur. The most prominent feature is the double maximum of equatorial rainfall. The principal maximum in Colombia occurs in the September to November quarter and the secondary maximum in the March to May quarter.[2, 3]

With only the narrow transition zone of northwestern Ecuador, the most thoroughly parched region of South America succeeds that area of most complete drenching. Relatively a few miles north of the Gulf of Guayaquil stretches mile upon mile a dense, almost impenetrable, tropical rain forest; a few miles to the south begin seemingly interminable lands of burning, desiccating, scorching desert, extending for hundreds of miles, far into Chile and Argentina — desert in which Iquique experiences rain but one day per year on the average. Rains over the entire region bring less than ten inches annually; a large section receives less than five inches. Chiclayo, in the north, records eight-tenths of an inch annually; Coquimbo, at the south, 5.2 inches; Oruro, on the tableland, 2.2 inches.

At the Isthmus of Panama the greatest mean annual rainfall shifts to the Atlantic coast and remains there through the Central American countries as may be seen from the data in Table 2.

TABLE 2.— RAINFALL ON THE ATLANTIC AND PACIFIC COASTS OF CENTRAL AMERICA.

Country.	Precipitation in Inches. Atlantic Coast.	Pacific Coast.
Canal Zone, Panama	128.4	68.8
Costa Rica	220.0	100.0
Nicaragua	150.0	75.0
Honduras	100–125	100–125
El Salvador		60.0
Guatamala	199.0	55.8

NOTE: These data are only approximate and cover only a few years of experience except for the Canal Zone.

Snow forms in great quantities within high clouds in all latitudes, but in the tropics it melts into raindrops as it falls, except where it strikes high mountains. In Peru comparatively little snow falls below 14 000 ft., and the line of perpetual snow varies from 15 000 to 17 000 ft. At the equator, the snow line approximates 17 000 ft. and at 20 deg. latitude, 15 000 ft.

Evaporation. Very few determinations of the evaporation from surfaces of lakes and reservoirs in the tropics have been made outside of the Canal Zone in Panama. The rate of evaporation in the Canal Zone is much higher during the dry season than during the rainy season, as the high wind movement, low humidity and vapor pressure, light cloudiness and high daytime temperature all tend to accelerate it. The quantity of water lost from the surface of Gatun Lake by evaporation during the four dry-season months is nearly as great as the evaporation during the eight months of the rainy season. The total annual evaporation ranges between 52 and 65 in.[4, 5]

Run-off. Very few measurements of run-off in the tropics have been made and then only intermittently during a few years. Reliable data relative to the run-off and floods of the Chagres River in Panama may be found in the references listed in the bibliography of this paper.

Earthquakes. From the sixteenth century to the present time there have been several earthquakes of destructive intensity in the Central and South American countries within the Torrid Zone. Quito, Ecuador, has suffered from repeated earthquakes; Caracas, Venezuela, was almost entirely destroyed in 1812; Cumana, Venezuela, was destroyed several times and most recently in January, 1929; San Salvador, the capital of Salvador, was partly destroyed in June, 1917, and again in 1919; Tegucigalpa, Honduras, was greatly damaged by an earthquake, followed by a fire, in July, 1933; Cartago, Costa Rica, was destroyed in May, 1910, and in March, 1924, partly destroyed together with San Jose, the capital, and three other towns.

Old Guatemala City, built on the flank of an extinct or almost extinct volcano, was ruined seven times by earthquakes from 1541 to 1775, and the new city, relocated close to an active volcano in 1779, was laid in ruins in December, 1917; Cucuta, Colombia, was almost totally destroyed in 1875; the last earthquake in Bogota, Colombia, destroyed a church on Guadaloupe mountain but caused little damage in the city; in December, 1923, there were several disastrous earthquakes in both Colombia and Ecuador; Managua, Nicaragua, was partly destroyed by an earthquake, followed by a fire, in March, 1931; Lima, the capital of Peru, and the nearby port of Callao, were almost totally destroyed in 1687 and 1746; Arequipa, Peru, has been destroyed several times.

The Canal Zone and Panama City appear to be located between the destructive earthquake belts in Central and South America as judged by the earthquakes which have occurred since the founding of Old Panama in August, 1519. Two destructive earthquakes have been reported, one in 1621 in Old Panama and the other in the existing city which is about six miles from the former. It is doubtful if a destructive earthquake occurred in 1621, as it is not mentioned in Mendosa's history. The earthquake in September, 1882, was of the greatest intensity of any of which there is a record on the Isthmus, but the damage was relatively slight. Part of the old municipal building fell, but it was very poorly constructed; cracks were opened in several buildings; slight damage occurred along the Panama railroad; and there was a tidal wave of small amplitude at Colon.

From 1909 to 1930, inclusive, the seismographs of the Panama Canal recorded 783 quakes, of which 83 were felt by residents in the Canal Zone. Only those felt by the residents were of relatively local origin, less than 200 miles distant. During July, 1934, a series of shocks occurred in Panama, with intensities as high as VII to VIII on the modified Mercalli Scale, at David and Puerto Armuelles in Chiriqui Province, located 195 and 230 miles, respectively, southwest of Panama City. A length of 400 ft. of the outer end of a reinforced concrete dock at Puerto Armuelles collapsed; several wooden houses slid off the posts on which they were set about 7 ft. above the ground; and the railway steel water tank was knocked down.

R. Z. Kirkpatrick, Chief of the Section of Surveys of the Panama Canal, has written as follows concerning earthquakes in the Canal Zone:[6, 7]

> One of the fortunate things Nature did was to put a sort of seismic safety valve, as it were, over 100 miles from the nearest part of the Canal, in Panama Bay. There are submarine palisades at the 100-fathom line in the bay, running from the west coast of Colombia along the ocean bed nearly to Costa Rica. The occasional little jolt that is felt in Panama and the Canal Zone is nearly always from out there; the safety valve is working to take up the undue earth stresses that have mounted a little high since the last readjustment.

No damage has been done to the reinforced concrete buildings, basins, reservoirs, and pipe lines of the water-supply systems constructed in the Canal Zone since 1904 by the shocks of light intensity which have occurred from time to time.

The Managua earthquake, in March, 1931, occurred in an almost dormant seismic zone. The city was partly destroyed by the earthquake, but the fire that followed burned 31 blocks, 15 of which were in the main business section. About 1 000 lives were lost and the property damage was estimated at $15 000 000. The damages were greatest along the fault line, but the extent of the zone of severe shocks was very small. The area damaged was about 6 miles long, east and west, by about 3 miles wide north and south.[8]

A circular reinforced concrete reservoir, 120 ft. in diameter and 15 ft. deep, constructed by R. W. Hebard & Co., New York, N. Y., in 1928–1929, on a foundation excavated in solid rock was not damaged. It was located about 1.9 miles from the point where the violence of the earthquake reached its maximum. The 12-in. supply main from the reservoir to the distribution system was pulled apart where it crossed the fault line, and the reservoir was emptied quickly.

A pumping plant had been built by the same company near the surface of Lake Asosoca, a crater lake with side slopes of 2 on 1, and equipped with pumps operated by Diesel engines. The station was buried by heavy slides in the steep banks of the lake; one pump was moved out of line, the suction pipe and many accessories were broken; and the other pump was damaged only slightly. As the work on the new water-supply system had been stopped in 1930, due to lack of funds, the permanent pumping station and retaining wall of reinforced concrete back of it had not been built.[9, 10] A welded-steel pipe line had been laid from the pumps to the top of the slope of the crater to join a cast-iron line leading to the reservoir. The steel line was ruptured and shortened 3 in. when the top of the crater rim was moved forward. The pumping plant was dug out; a retaining wall was built to protect it against slides; and the engines and pipe line were repaired so that pumping was resumed on April 20, 1931.

From these data, it is evident that earthquakes of varying intensity are of not infrequent occurrence in most of the tropical countries and must be taken into consideration in designing water-supply systems. From the investigations of earthquakes it is evident that properly designed buildings of reinforced concrete, or of structural steel, will withstand severe earthquakes with minor damages, if any.

The writer is of the opinion that wash-water tanks should be kept out of a head house or filter building. At many sites the topography is such that reinforced concrete tanks may be built on the ground a short distance from the filtration plants; if not, an elevated steel tank, with proper foundations, should be provided. In large cities, it is advisable to place distribution reservoirs on both sides of earth faults which are known to exist as the result of earthquakes which have occurred. Consideration may also be given to the installation of a self-acting valve in the supply main near the reservoir to prevent the loss of all the water if the main is broken.

Miscellaneous Phenomena. Thunder-storms occur frequently in most tropical and equatorial regions of heavy rains; on the Isthmus of Panama, they occur seldom during the dry season but frequently during the rainy season. Hailstorms are unusual in the lowlands of the tropics, although there have been a few in the Panama Canal Zone, but they occur frequently in the mountainous regions.

The northern part of the Torrid Zone is not subject to hurricanes, but their influence is often felt in high wind storms which do great damage to the banana plantations. Most of the storms on the Isthmus of Panama are local, of short duration, with the wind reaching a velocity of 40 miles per hour occasionally. Practically the only general storms that reach as far south as Colon are the "Northers," brisk northerly winds, ranging in velocity up to 30 miles or more per hour, accompanied by heavy rainfall at times. Cyclonic storms do not extend southward beyond the tropic of Cancer.

Influence of Climate and Altitude on Water Supply Projects. The survey of a watershed extending into a region located at elevations ranging from 10 000 to 12 000 ft., or higher, is subject to many difficulties and delays. The work must be suspended frequently on account of poor visibility or violent magnetic storms. It is difficult to obtain laborers to work and live at a high altitude. There are no pastures for horses and mules, and it is difficult to keep them near a camp. The food supplies must be transported on mules or burros over long distances and are subject to delays. Some of the members of a party are always affected adversely by the altitude and the climate, with the result that they must quit or frequently return to lower altitudes. On the other hand, surveys and construction work in the coastal lowlands are slowed up by heavy rains, high temperatures and high humidity and are subject to frequent suspensions.

Obstacles to Spanish-American Work. To offset the advantages resulting from the absence of frost, snow and ice in the populated areas of the tropics, there are the complications due to heavy rains, earthquakes, inadequate transportation facilities, lack of trained labor, and the multitude of holidays. The customs and laws of the various countries, the vicissitudes in the rates of exchange, and the frequent changes in the personnel of the governmental department that has direct charge of the work must all be taken into account.

The greatest difficulty in carrying out contracts in Central and South America results from the failure of the representatives of North American companies, either due to indifference or to a narrow-minded attitude, to study the customs, mannerisms, etiquette, local conditions, and lines of reasoning of the Spanish American. Companies with an excellent reputation for their work in the United States often fail to make satisfactory progress on a contract in South America.

Cost-plus contracts have been one of the greatest sources of friction between foreign construction companies and departments of public works

because the cost of projects exceeded the original estimate long before the projects were completed. Another source of friction develops from the failure of a contractor to make a thorough preliminary investigation of a project upon which he bids, with the result that its completion is delayed by conditions encountered during the work and the cost is greatly increased.

Oftentimes a project in Spanish America cannot be developed according to the rules and methods used by engineers in their practice in the United States. The temperament and method of reasoning of the Spanish American must be given proper consideration in working out a problem, otherwise the foreign engineer will find that his conclusions and recommendations are not acceptable even though his professional standing is of the highest.

In spite of exaggerated reports of revolutions, North Americans must bear in mind that the Spanish American has a keen and clever mind, able to detect weak points in projects and that, in certain sections, he has developed the art of trading to a fine point. With few exceptions, at the present time, the North American engineer works under a handicap, because he underestimates the capability of the men with whom he is negotiating.

In making an investigation of the sources of water supply available for a Spanish-American city one is greatly handicapped by the lack of maps and records of rainfall and stream flow. The lack of roads adds another problem. Aerial surveys are rare.

Some municipalities have installed hydro-electric plants on one or more small rivers and conveyed the water to tanks at lower levels from which there is gravity flow to a system of open canals in the streets or to an incomplete distribution system of cast-iron or steel pipe. On such projects, the development of power and light as a source of income for the municipality is given first consideration, and the water supply is regarded somewhat in the nature of a by-product. Such cases have produced records of stream flow over a period of a few years.

A city that has grown rather rapidly and is not situated near a large river may have developed water supplies from five or six small streams nearby, each one serving a new district into which the population has expanded. A record of the volume of water flowing over a weir into the distribution system connected to each supply may have been kept for several years, but measurements of the total stream flow past the intakes may not have been made. As the population increases, a shortage of water develops during the driest months of each year, and 24-hour service cannot then be maintained.

Surface Water Supplies.

Municipalities that are large enough to install a water supply usually take the water from a surface stream if one is available within a relatively short distance. Most of the small rivers and their tributaries, that are used as sources of water supply, are swift-running streams with water-falls, rapids, and many rocks to churn the water over and over so that conditions

are not favorable for effective reduction of bacteria by natural purification. The catchment areas of such streams are generally quick-spilling with the result that feces deposited upon the surface of the ground are swept rapidly into the nearest tributary.

The forest has either been removed or is being removed from many of the catchment areas for sale as lumber in the nearest city, with the result that the run-off during heavy rainfalls erodes the surface stratum of clay and carries large amounts of it into the rivers. In cases where measurements of stream flow have been taken over a period of years, it has been observed that the minimum flow during the dry seasons has decreased since the forest was removed. Reforestation is practically unknown.

The majority of the catchment areas of surface streams are subject to pollution by people living on them or by traffic over the public roads

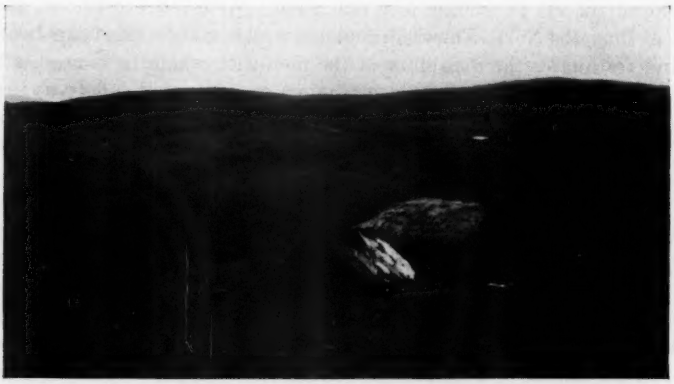

FIG. 1.— TYPICAL HABITATION ON PLATEAUS AT ELEVATIONS OF 10,000 TO 12,000 FT. ABOVE SEA LEVEL.

which almost invariably cross the catchment areas. Little attention is given to the enforcement of sanitary regulations. Laws exist and additional ones may be obtained easily, but their enforcement is difficult, sometimes because funds are lacking to maintain inspectors, sometimes because of the political influence of the residents, and sometimes because city officials have no desire to enforce the regulations and are not compelled to do so. The writer recalls one case where there were several sources of pollution above and relatively close to the intake of the water supply to which attention was directed several times, and even pointed out to the proper official during an inspection, without any action being taken to make the offending parties install septic tanks or sanitary privies.

In many cases, the families living on a catchment area are too poor to buy the materials for the simplest type of sanitary privy. The alvine discharges are often deposited directly upon the ground surface close to the

habitations and left uncovered. Household slops and garbage are also thrown upon the ground, but most of the latter is consumed by half-starved dogs and other animals. Baths are taken in the nearest stream, and the family washing is done in it. In such cases, the municipality should provide the funds for septic tanks or sanitary privies, but officials generally consider it more essential to use the income from the sale of water for improving streets, building slaughter-houses, or extending the distribution system.

In the case of a small college on one catchment area, with about 100 students, the writer did succeed in having a septic tank installed, because it was quite evident that something had to be done after it had been

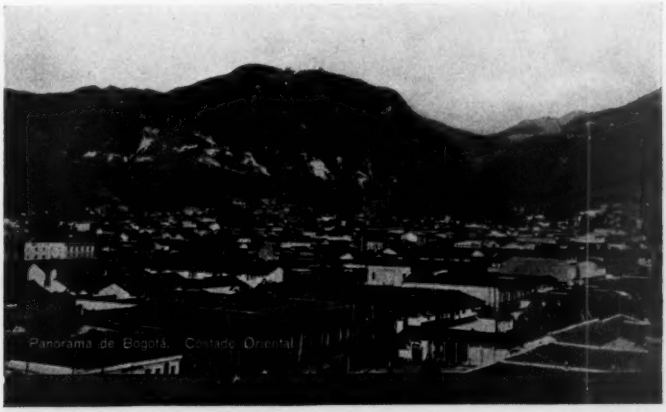

FIG. 2.— MONSERRATE CHURCH AND CATCHMENT AREA OF SAN FRANCISCO RIVER, BOGOTA, COLOMBIA, S. A.

The church is situated on the hill in the left background. San Francisco River passes through the gorge in the right background.

demonstrated that outbreaks of typhoid fever and dysentery during the preceding five years in the city had been caused by the sewage entering a small stream which flowed into the river a short distance above the intake for the water supply. An investigation and report on such a case by a foreigner will accomplish more than one made by a local official, because the former may be used as a buffer against any criticisms that may develop and the blame for remedial action placed upon him.

In a few cases, cities have purchased the catchment areas from which their water supply is taken, moved off the inhabitants, and left only a few houses for use by caretakers stationed at various points to keep off squatters and trespassers. However, the public roads crossing catchment areas have not been closed so that the tributaries to the main streams are still subject to pollution by people driving trains of burros carrying vegetables, fruit, flowers, etc. to the city during the forenoon and returning in the afternoon.

Of course, the dangerous pollution comes from the persons accompanying the animals as they use any point of the roadway as a privy. The author has never yet seen a catchment area in the tropics, large or small, that was not subject to some pollution by people living on or traveling over it, and he considers an inaccessible watershed to be a myth.

The most glaring example of pollution of a water supply observed by the author was one found during an investigation of the water supplies of Bogota, Colombia, in 1921. Part of the catchment area of the San Francisco River, from which water was taken for one section of the city, consisted of the south and east slopes of Monserrate Hill on the top of which a church

FIG. 3.— STRING OF SHACKS BACK OF MONSERRATE CHURCH WHERE FOOD IS COOKED AND FRUIT SOLD TO VISITORS.

The ground back of these shacks slopes steeply to tributaries of the San Francisco River.

of the same name was situated. Every Sunday from 600 to 2,000 people visited this church and, as no privies were provided, the churchgoers scattered their alvine discharges over the ground surrounding the church. Thus, excreta containing pathogenic organisms, for many of the people visiting the church were suffering from one ailment or another, were deposited on Monserrate Hill and intermittently carried down into San Francisco River by rains with the result that a more or less endless chain of infection existed. This case furnished the clearest demonstration of the transmission of typhoid fever and dysentery by a water supply encountered by the author in 32 years of experience in water-supply investigations.

At the same time an inspection was made of the catchment area of the San Cristobal River from which water was taken for another section of Bogota. On a trip over one of the roads near the river, 52 persons and

42 burros, oxen, and pigs were encountered in 35 minutes of riding over a short section. The road was spotted with feces of the different animals while the excreta of human beings were observed along the side of the road. It was estimated that about 3 000 persons passed over this road each week on their way to market in the city and again on their return to the country. A short distance above the intake, a section of a road running close to the river was converted into a public latrine. Under such conditions, it was not surprising that the mortality from typhoid fever and dysentery was excessively high in the district supplied by water from this river.

The conditions in Haiti, as reported by Butler and Choisser, are duplicated in many districts in the tropics. These authors give the following causes for the general contamination of the water supplies:[11]

Intense and universal soil pollution by human and animal excreta.

The sponge-like porosity of the country rock (limestone) which exercises little or no filtering action upon the rain water which falls upon the surface but carries down freely the surface pollution and brings it to the surface at the springs and sources unchanged in this regard.

The heavy contamination of every stream of running water and every lake in the Republic by (a) intense soil pollution of the banks and shores and (b) contamination of the water by washing of the clothes of human beings and the bodies of men and animals.

In the high mountain regions of Haiti where water is obtainable only from water holes, there is intense contamination and gross pollution of the water by human and animal discharges. Many of these water holes simply reek with filth and yet the water is consumed by human beings without treatment.

At such special watering places as Sources Chaudes de Jéréme* and Sources Chaudes de Terre Neuve*, places which could be made to serve "Hygieia" most admirably, such unspeakable conditions of filth and overcrowding exist as to make them more liable to spread disease, than to cure it.

Lastly in this bill of complaints is the dangerous piece of apparatus used throughout rural Haiti literally by hundreds of thousands of people to carry water from the sources and water courses for family use. We refer to the calabash and will say if the special knowledge of the trained bacteriologist and sanitarian had been called upon to plan a perfect piece of apparatus for conferring the water-borne diseases upon human beings, it could not have devised a more diabolical thing than the calabash as used today in Haiti. (The gourd-like fruit of the common calabash tree. The largest specimens have a capacity as great as 8 liters.) First, this "Nectar haitiensis" cannot be filled without contaminating the water by human hands; second, as ordinarily seen on trips to and from the house, the person inserts the finger into the filler opening and contaminates the entire water contents for a second time. Third the water cannot be sterilized by legitimate amounts of chlorine or iodine introduced into the calabash before using. The entire dosage of chlorine or iodine is "absorbed" by the organic matter of the calabash itself.

The matter of the calabash is a difficult one. It is very likely that this apparatus inoculates or vaccinates all rural Haitians with dysentery and typhoid fever at an early age, so that those who grow to maturity represent the survival of the fittest and are henceforth immune to these several filth-borne diseases.

Salt springs are not an uncommon occurrence on catchment areas. Before interpreting a high chloride content as evidence of sewage pollution, it is necessary to determine whether or not salt springs exist. On one occa-

*Author's Note: These are hot springs.

sion, the writer found that a small quantity of salt was being produced on a catchment area by evaporating the water from salt springs. On a second occasion, the presence of about 150 p.p.m. of chlorides as Cl in a small river during a period of minimum flow, as compared to 15 p.p.m. during a period of normal flow, lead to the location of several warm salt springs, at a short distance above a proposed intake for a water supply. These springs had a chloride content of about 6 000 p.p.m. On a third occasion, two hot springs were found with a high mineral content and a local reputation for therapeutic value.

Natural lakes from which a water supply may be taken are rarely encountered within a relatively short distance of cities. The source of supply for the new water works installed a few years ago at Managua, Nicaragua, is Lake Asososca which covers an area of 240 acres, has a depth of 900 ft., and is located only 2 miles west of the city. Nicaragua has two very large lakes: Lake Nicaragua — the largest body of fresh water south of the Great Lakes of Canada and the United States, and north of Lake Titicaca in Peru and Bolivia — and Lake Manafua.

There are no large lakes in Colombia, Ecuador, Panama and Costa Rica. Many small lakes are found in the Andean region of Peru at high elevations, but they are too far from the cities to serve as water supplies. In most cases, these lakes are the sources of the inter-Andean rivers or of the short streams leading to the coast. Salvador and Guatemala have a number of beautiful lakes, but none of them are used for water supplies.

Impounding reservoirs for municipal water supplies do not exist, and few will probably be built for many years to come, as money for their construction has not been, and will not be, available in the near future. The first large dam in Colombia is now under construction to impound 1.2 billion gallons of water for the new supply for Bogota. In the Panama Canal Zone there is Gatun Lake, with an area of 164 sq. miles and a useful storage capacity of 240 billion gallons of water at elevation 87.0 ft. above sea level, but this reservoir was built primarily for the operation of the Canal locks, although the water supplies for the communities at the Atlantic and Pacific ends of the Canal, including the cities of Colon and Panama in the Republic of Panama, are now taken from this lake. Madden Dam, recently completed on the Chagres River, has formed a new impounding reservoir in the Canal Zone, with a capacity of 165 billion gallons of water at normal water level, for the storage of water for the locks, the regulation of floods on the Chagres river, and the development of electric power.

Ground Water Supplies.

A few of the largest cities and several of the smaller ones have developed ground water supplies. Lima, Peru, with an estimated population of 207 000 in 1930, obtains the greater part of its supply from infiltration galleries at a point about 4 miles northeast of the city. The ground water

is clear and colorless but has a soap hardness of about 208 p.p.m. Chlorination of the ground water was started in March, 1916, and has been continued up to the present time. During an inspection by the author, a few months after chlorination was begun, it was discovered that when bedtime came, the operator shut off the chlorine until he arose on the following morning, although the water continued to run into the distribution system.

As the yield from the infiltration galleries is insufficient to take care of the consumption in Lima and its suburbs, water from the Rimac River is added to the ground water. When the river water is turbid, it is clarified by alum and sedimentation before it is mixed with the ground water.

The water supply of Callao, the principal port for Peru, with a population of about 61 000, is derived from wells. The water is slightly harder than that of the Lima supply. The supply has been chlorinated for several years. There are 22 other municipalities in Peru in which water works have been installed, with populations varying from 1 700 to 56 000. Of these supplies, 6 are derived from springs, 7 from rivers and 9 from wells and infiltration galleries.

The water supply for San Salvador, the capital of El Salvador, with a population of about 100 000, is taken from springs on the edge of the city and is chlorinated.

For about 28 years, Cartagena, Colombia, with a population now estimated at 70 000, has struggled along with an inadequate supply of water collected from springs located nearly 13 miles outside the city. The soap hardness is 212 p.p.m. Depending upon the yield of the springs, situated in a region of very erratic rainfall, it is estimated that the water available for use varies from 7 to 17 g.p.d. per capita. Nearly all of the houses are provided with cisterns or tanks in which rain water is stored. The circulation between a cesspool and an underground cistern of the older type was demonstrated clearly by a friend of the author who dumped a quantity of potassium permanganate into a cesspool and about four hours later found the water in the cistern colored pink.

San Jose, the capital of Costa Rica, obtains the greater part of its water supply from springs about 8 miles outside the city and the remainder from a river. The river water is filtered through slow sand-filters and is chlorinated.

Iquique, a port near the north end of Chile, at a latitude approximately 20 deg. south, furnishes an example of the difficulty and expense involved in obtaining a water supply in a desert, as it is necessary to run a pipe line 75 miles inland to obtain ground water.

Water Supplies for Small Communities.

The provision of potable water to the numerous small communities scattered throughout the tropics is a public health problem which involves from 70 to 88 per cent. of the total population. Up to the present time, ittle progress has been made in solving this problem. Many of the com-

munities obtain their water supplies from springs, shallow wells and surface streams with kegs carried by burros, or kerosene or gasoline cans carried by hand, serving as a means of distribution. In some places, the run-off is conveyed through ditches into small artificial ponds which serve animals and inhabitants alike. These ponds form a very picturesque sight when they are covered with a luxurious growth of algæ and water plants with women filling cans with water and cows defecating a few feet away.

Lack of funds is responsible for the conditions that prevail, and there appears to be no hope of any great improvement in the near future. The author believes that the installation of drilled wells offers the solution in many cases of obtaining a supply of potable water even though distribution systems cannot be installed. A number of such wells have been drilled with good results in the interior towns of the Republic of Panama. The weak point of such wells is that proper attention is seldom given to the prevention of the entrance of surface water unless a sanitary engineer of the Government is available to enforce the necessary precautions.

Dr. John D. Long, of the United States Public Health Service, has published some striking evidence of the results obtained by providing small communities with potable water from wells drilled in the Philippine Islands. In some of the communities in which wells were drilled, the proportion of deaths decreased 50 per cent. during the first year after good potable water became available. This improvement was due to a decrease in intestinal illnesses, dysentery, etc., and was noted especially among infants. Such results in a short period of time, other influences remaining unchanged, demonstrated in a conclusive manner that the change from a polluted water supply to a pure and wholesome supply effects a material decrease in the general death rate. The author believes that equally good results would be obtained in many of the small communities in Central and South America providing the wells are properly drilled and protected against contamination.

Temperature of Water Supplies.

The temperature of the water supplies in the Panama Canal Zone may be taken as representative of those prevailing in warm coastal cities in the tropics. The temperature of the water in the Brazos Brook and Agua Clara reservoirs as withdrawn between the surface and a depth of about 6 ft. fluctuated through a range of only about 7°F. from a minimum of 80 to a maximum of 87°F., during a typical year. The temperature of the raw water as received at the Mt. Hope and Agua Clara filtration plants after flowing through cast-iron pipe lines, not exceeding 1.5 miles in length, partly buried and partly exposed, remained within the same range with a few exceptions. The temperature of the filtered water as it left these plants also fluctuated through a range of 7°F. from a minimum of 79 to a maximum of 86°F., during a typical year. The average drop in temperature between the raw and filtered water at the Mt. Hope plant was only

1°F. with a maximum drop of 1.5°F. At the Agua Clara plant, the temperature of the filtered water varied by a few tenths of one degree above or below that of the raw water.

On January 7, 1916, the temperature of the raw water entering and leaving the aëration basin at the Mt. Hope plant was determined each hour during a period of 24 hours. The temperature of the raw water fluctuated through a range of only 2.2°F. from a minimum of 83.1 to a maximum of 85.3°F. The maximum reduction in the temperature of the raw water effected by aëration through cone spraying-nozzles was 1.2 and the minimum 0.7°F. The trade winds were blowing with a maximum velocity of about 15 miles an hour during this test. The air temperature, as determined in a standard instrument shelter, 8 ft. above the ground, varied from 77.4°F., at 6 A.M., to 82.4°F., at 2 P.M.

The temperature of the raw water, as pumped from an arm of Gatun Lake at Gamboa to the Miraflores filtration plant through 11.3 miles of buried cast-iron pipe, fluctuated through a range of 5°F. from a minimum of 79 to a maximum of 84°F. during a typical year. There was an average drop of about 1°F. between the raw and filtered water at this plant, and the range between the maximum and minimum temperatures of the latter was 5°F.

One outstanding advantage of treating water supplies of the above temperatures is that the mixing time required for flocculation is greatly reduced. At the Miraflores filtration plant, the floc is formed during a mixing period of about 4 minutes in chambers with baffles of the over-and-under type. Such a short mixing period permits making a reduction in the size of mixing units and the cost of filtration plants.

As withdrawn from the street mains in Panama City and Colon, the filtered water averages close to 81°F. throughout the year. This is almost ideal for shower baths with the result that a large proportion of the population never uses hot water. Tub baths are taken by relatively few of the people who have lived on the Isthmus more than one year.

A disadvantage of water of such a temperature is that very few persons will drink it without cooling it either by ice or by storage in bottles in a refrigerator. On practically all the field jobs in the Canal Zone, water coolers are provided for the personnel; one for white foremen and another for colored laborers.

In the low-lying, warm coastal cities, the temperature of the water supply, if taken from surface streams, will fluctuate between 80 and 84°F. At altitudes of 3 000 to 4 000 ft. above sea level, there will be a fluctuation between 64 and 72°F.; and at altitudes of 8 000 to 10 000 ft. between 46 and 55°F.

As taken during the months of June to August, 1918, the average temperature of the water obtained from the infiltration galleries at Lima, Peru, was 70.7°F. The depth of the galleries below the surface of the ground varied from 13 to 38 ft. The temperature of the water flowing in

the Rimac River, approximately 1.5 miles distant from these galleries, was 66.2°F. This river originates in the snow-capped mountains of the Andes. The temperature of waters from four wells at different points in Lima, with an average depth of 142 ft. and a diameter of 4.5 ft., was 71°F.; the depth of water in these wells averaged about 13 ft. The average air temperature at Lima is 68°F.; the minimum is 52 and the maximum 84°F. The city is located at an average elevation of 478 ft. above sea level, about 7.5 miles from the Pacific Ocean, at latitude 12 deg. 4 min. 13 sec.

Estimates of Population.

One is handicapped greatly in fixing the capacity of a filtration plant in a Spanish-American city by the lack of accurate statistics concerning population and consumption of water. Official enumerations of population have been taken only within the last 20 years in most of the countries. Possibly the data from three or four censuses, taken at irregular intervals, may be available. The census reports from the larger cities often show greater populations than actually exist, due either to errors in enumeration, padding on account of rivalry between cities, or to political reasons. Occasionally, after a census has been taken, it will not be approved by the government of the country, because it is quite evident that the populations reported by many of the cities are too large.

Other sources of information relative to population which are available in many cities in the United States are not found in Spanish-American countries, although conditions are improving in this respect and more attention is being given to the assembly and preparation of statistics than has been the case during years past. The best rapid check on the population may be obtained by multiplying the number of houses by the average number of persons per house. This varies between 6 and 11. However, it is often difficult to ascertain the correct number of houses, as of a certain date, from the municipal department of statistics. Occasionally, one finds that a fairly accurate record of the number of houses and occupants is kept by the office of the health department in connection with campaigns to improve sanitary conditions.

An estimate of the population by municipal authorities in the years between censuses is made by bringing the figures of the latest census up to date by an annual rate of increase based on arithmetical or geometrical progression. In some countries, the annual rate of increase to be used is fixed by the government.

The populations obtained from an official census taken in 1928, or during the period of inflation which occurred thereabout, should not be used during the years of depression which followed. With few exceptions, the populations of the principal cities have shrunk greatly during the years of depression, because many persons who moved to the city from the surrounding country to work during the boom period were forced to return

as the depression gained headway. Cities that were reported to have a population of about 115 000 near the end of 1928 now have a population nearer 80 000.

Occasionally, a city is found in which the population has suffered only slight reduction, or in which the reduction, though of considerable extent, has been offset by recent growth and expansion into the suburbs. Such cases are the result of conditions peculiar to each city.

Estimates of the future population of cities in Spanish-American countries have been made in several instances by North American consulting engineers by plotting the curves of several cities in the United States, but the author is skeptical of estimates prepared by this method. Local conditions and factors existing in the cities of the United States in the past are entirely different from those in Spanish-American cities, and such differences will continue to exist. The relations between birth and mortality rates, immigration, manufacturing, and business developments in the two countries are not comparable.

The author is unable to give a rule for estimating the future population of Spanish-American cities. Each city must be considered as a different case, depending upon its location, transportation facilities, products available for export, manufacturing developments, etc. The best ingenuity of a consultant must be exercised to make a reasonably approximate estimate of the future population of a city or, better, a close guess.

Occasionally, committees of local officials or municipal councils will establish the population for which a water supply shall be designed with the idea that the plans shall be made so as to permit extensions to be made as and if the population increases. To an impartial observer, the estimate of future population in such a case often appears to be greatly exaggerated, but there are some advantages in such a scheme if the source of the water supply permits the expansion of the water works to the extent necessary and if an area of size and topography suitable for a filtration plant is available. Occasionally, the capacity of the water supply system is established so that the population and per capita consumption do not have to be estimated by the consultant.

Estimates of Water Consumption.

Estimating the per capita consumption of water in Spanish American cities is also a difficult problem due to the lack of necessary data, Venturi meters, or any other types of meters, are conspicuous by their absence. In cities in which water works have been in service for a few years, a rough idea of the consumption may be obtained if measurements of the water entering the distribution system, or of the flow in a canal discharging into a distributing reservoir, have been made by weirs. Pumping stations in which measurements may be made are found only rarely.

The author has found that a Pitot tube, with a manometer or a recorder, may be used to great advantage in obtaining measurements not

only of the volume of water entering distribution systems during a period of 24 hours but also during each hour. However, this equipment must be provided by the consulting engineer, unless it has been ordered previously at his request. In some cases, a distributing reservoir may be divided into two parts so that one is available for measuring the flow into the distribution system.

In many cases, the existing distribution system in a city covers only a part of the total area occupied by the houses and buildings, so that the population supplied must be obtained before estimating the per capita consumption from the volume of water flowing into the system. Furthermore, public hydrants are generally provided for the poor people, and water is taken at such points, or from springs, and distributed in kegs or other containers to the houses not connected to the distribution system. In most of the smaller cities, there is a constant flow of water from the public hydrants; this may be the case also in larger cities, or hydrants may be in service that must be opened by the persons taking water and that close automatically when the hand is removed from the valve.

A case, such as the following, is not unusual. A supply of ground water varying between 300 000 and 700 000 g.p.d., depending upon the yield of springs, is entirely inadequate for the population of 60 000, in a city near the coast. The pressure is too low to distribute water throughout the houses, so that the owner of each house provides a small tank in the ground to receive the water flowing from the service pipe. From this tank, he lifts the water by a hand pump to a small elevated tank, or a group of gasoline drums, from which it flows to the kitchen and bathroom. Most of the houses are also provided with cisterns for storing rain water to be used during the dry months.

In such a case, what should be assumed as the per capita consumption when an adequate supply of filtered water under suitable pressure becomes available? Is it to be expected that the per capita consumption will remain low because of the restricted use of water with the old supply or will it double or treble?

It is quite certain that the younger generation will soon forget the restrictions formerly placed upon their use of water. As the climate is hot, more water will be used for bathing, and people who have been forced to take their baths in the sea will use a shower bath more frequently. Water closets will be installed in the old houses to replace privies, and in the new houses more bathrooms and fixtures will be installed than in the old houses. The distribution system will be extended to suburban developments which have been held back by the lack of water. The leakage from the distribution system will increase, and more water will be used for gardens, flushing streets, etc.

The author is of the opinion that 50 g.p.d. per capita is the minumum consumption which should be assumed for the new water supply service. This estimate is based on the meterage of all services and on a rather high

rate of $1.25 per month for the first 15 000 gallons for houses valued at more than $550. If meters are not installed before the filtration plant is placed in service, the consumption may run as high as 80 g.p.d. per capita.

A second representative case follows. The population of the city in question is approximately 90 000. The surface water supply is adequate, and the pressure is sufficient to distribute the water through four-story buildings except during the hours of heaviest consumption. The consumption approximates 80 g.p.d. per capita, and the waste of water is excessive. The distribution system covers the greater part of the central district of the city. The altitude is about 3 500 ft. above sea level; the days are a little warm and the nights comfortably cool without being chilly.

Because of several epidemics of typhoid fever and dysentery, it was decided to build a filtration plant. Before the plans could be made, it was necessary to decide upon the capacity of the plant. The author decided that 66 g.p.d. per capita was a fair allowance for consumption with all services metered. The plant was designed on this basis and constructed, but the funds were not available for the purchase and installation of meters.

The local authorities believed that the waste of water could be reduced and held to a reasonable amount by a house to house inspection with compulsory repair of leaky fixtures and by newspaper appeals for co-operation by consumers, but after the filtration plant was placed in service the consumption steadily increased to about 100 g.p.d. per capita, with the result that the nominal capacity of the plant was insufficient to meet consumption. The inspection service and the newspaper campaign to reduce waste of water proved to be a failure, and it was not until meters had been installed on about 67 per cent. of the services in use that consumption was reduced to approximately 66 g.p.d. per capita. Additional details concerning the reduction of consumption in this city by metering are given in a later section of this paper.

Instead of trying to estimate the per capita consumption of water by cities 15 or 20 years hence and basing the initial capacity of filtration plants on the consumption that will prevail at that time, on the assumption that meters will be installed on all services and consumption will be reduced to that in systems with a small amount of "unaccounted for" water and with a low domestic use, the author is of the opinion that the initial capacity of filtration plants should be based on the actual consumption at the time they are built. If it is quite evident that an existing water supply is entirely inadequate in respect to volume and pressure, an estimate of the probable per capita consumption with an adequate supply must be made. The author's opinion is that in general 50 g.p.d. per capita is the minimum consumption which should be assumed for a city within the tropics. A fact not to be overlooked, or cast aside lightly, is that consulting engineers and local officials associated with them will be severely criticized if the initial capacity of filtration plants is not sufficient to meet the consumption of

water when they are placed in service under the conditions existing at that time, be they what they may.

These statements hold equally true for ground water supplies that are to be developed and do not require filtration. The development of a water supply which is adequate for only part of the population of a city is a short-sighted policy, but there have been cases in Spanish-American cities in which such a policy has been followed.

A consideration of the factors that determine the consumption of water in Panama City and Colon is helpful in preparing an estimate of the per capita consumption in other cities in the tropics in which the conditions are similar in many respects.

Water Consumption in Panama City and Colon. In 1904, when the Isthmian Canal Commission started the preliminary works for the construction of the Panama Canal, the population of Panama City was about 18 000. The better class of buildings, from one to three stories in height, was constructed of masonry and wood, with the usual interior courtyards, known as *patios;* there were also small wooden shacks and palm-leaf huts. As in other Spanish-American cities, the blocks were entirely covered by buildings. The population of Colon, at the Atlantic end of the Canal, was about 8 000, and the structural conditions were similar to those in Panama City.

A member of this Association, Carleton E. Davis, went to the Isthmus in July, 1904, to take charge of the construction of the water works and sewerage systems and presented a paper[12] on his work at the 25th Annual Convention in which he stated:

> There were a few drains, some of them very old, but the city had never had a public water supply. The inhabitants depended entirely upon rain water collected in tanks and cisterns, and upon a few wells on the outskirts of the town. Water was sold from house to house at one cent gold per gallon. At the height of the dry season, when cisterns and tanks were exhausted and the wells were low, considerable actual suffering for lack of water frequently occurred among the poorer classes.
>
> The water works for the city of Panama were taken up first and pushed in advance of any others. It was estimated that the city would have a future popluation of thirty thousand. There is no manufacturing in Panama now, and probably never will be. The character and habits of the population are such that a large consumption of water need not be expected. Two million gallons per day, or about sixty gallons per capita, was taken as the necessary amount to supply.

The water was first turned on in Panama City on July 4, 1905, when 3 to 4 miles of the distribution system had been completed, and by the middle of 1907 the water works, sewers and paving had been completed. There were 2 093 house connections, 1 048 meters, and 133 fire hydrants. Practically all the houses were connected to the street mains and sewers. The Sanitary Department required the filling in of wells and cisterns and the removal of all rain-water receptacles.

The water supply was taken from an impounding reservoir on the Rio Grande River about 10 miles from Panama City. A partial reduction in

color, turbidity and iron was effected by passing the water through pressure filters without preliminary sedimentation, using ammonia alum as a coagulant. In March, 1915, the Miraflores rapid sand-filtration plant, with a nominal capacity of 17 m.g.d. was placed in operation by the author. The source of raw water was changed to the Chagres River arm of Gatun Lake at Gamboa from which the water was pumped to the plant through a line of 30- and 36-in. cast-iron pipe, 11.3 miles long. With this plant in operation all of the water supplied to Panama City and the Pacific end of the Canal was filtered and of excellent quality.

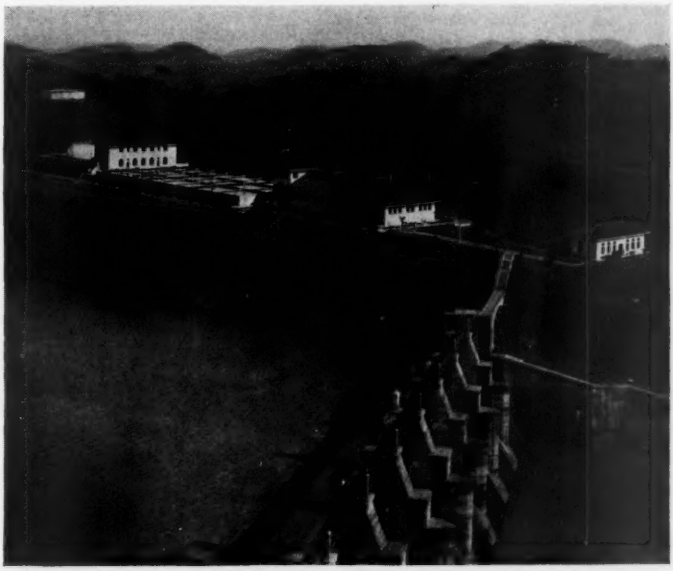

FIG. 4.— MIRAFLORES RAPID SAND-FILTRATION PLANT, PANAMA CANAL ZONE; NOMINAL CAPACITY, 17 M.G.D.

Near the end of 1914, the population of Panama City was 55 000; there were 2 300 metered services; the daily per capita consumption of water was 65 gal.; and the consumption, exclusive of water used for public purposes and "unaccounted for," was 40 g.p.d. per capita. In 1923, with a population of 59 458, the average daily consumption of water in the city for all purposes was 3 092 000 gal., or 52 g.p.d. per capita, and the number of metered services had increased to 2 529. In 1935, the population had increased to approximately 78 000 and additions had been made to the distribution system by developments in the suburbs. The average daily consumption of water for all purposes was 3 888 000 gal., or 50 g.p.d. per capita, and the number of metered services had increased to 3 018. About 23 per cent.

of the volume consisted of water used for fire service, hydrant testing, sewer flushing, and "unaccounted for." The average daily consumption of water as measured by the meters on the services was 2 993 000 gal., or 38 g.p.d. per capita. There is little difference in the consumption of water during the wet and dry seasons.

Work on an improved water supply for Colon was started in 1905, and an impounding reservoir was constructed on a small stream known as Brazos Brook, about 3.5 miles from the city. The water was pumped through pressure filters into the distribution system. In February, 1914,

FIG. 5.— MT. HOPE RAPID SAND-FILTRATION PLANT, NEAR CRISTOBAL, PANAMA CANAL ZONE.

Supplies filtered water to Colon, Republic of Panama, and to population in the Canal Zone; nominal capacity, 8 m.g.d.

a modern rapid sand-filtration plant, of 8-m.g.d. capacity, was placed in service.

Near the end of 1914, the population of Colon was approximately 17 000; there were 1 000 metered services; the daily per capita consumption of water was 71 gal.; and the consumption, exclusive of water used for public purposes and "unaccounted for," was 40 g.p.d. per capita. In 1923, with a population of 29 000, the average daily consumption of water for all purposes was 1 798 000 gal., or 62 g.p.d. per capita, and the metered services had increased to 1 121. In 1935, the population was estimated at 30 000; the average daily consumption of water for all purposes was 2 193 000 gal., or 73 g.p.d. per capita; and the number of metered services was 1 280. About 36 per cent. of this volume consisted of water used for fire service, hydrant

testing, and "unaccounted for." The average daily consumption of water, as measured by the meters on the services was 1 131 000 gal., or 38 g.p.d. per capita. While the per capita consumption based on the water passing through the metered services is the same as that calculated for Panama City, the per capita consumption for all purposes was greater in Colon. The loss of water from underground leakage in Colon is greater than in Panama City, because the greater part of the distribution system in Colon either comes in contact with salt water or lies in ground with a high salt content. There are also other factors, peculiar to Colon, that raise the per capita consumption.

The normal water pressure in the old sections of Panama City is 35 lb. per sq. in. and in the new sections 50 lb. per sq. in., but in the case of fires this is raised to 100 lb. In Colon, the normal water pressure is 45 to 55 lb. per sq. in. which is increased to 100 lb. for fire service.

There are certain conditions that tend to hold down the consumption of water in Panama City and Colon to 50 and 73 g.p.d. per capita, respectively. All the services are metered, and the rates are 35 and 45c., respectively, per 1 000 gal. with a discount of 5c. per 1 000 gal., if the bills are paid within 16 days following the end of the quarter. The water entering the distribution system is measured by Venturi meters, and the volumes are checked against the totals obtained from the readings of the meters on the services. The distribution systems, meters and collections are supervised by experienced employees of the Panama Canal. All installations and plumbing work are made under the control of inspectors of the Panama Canal.

There are a large number of tenement houses in which West Indians live in one and two room apartments. Batteries of water closets, shower baths, and laundry tubs for common use are provided on each floor. The owners of the tenements keep close watch of the plumbing fixtures to eliminate leakage and waste, as there is only one meter on the service to each building. The regulations stipulate that irrespective of occupancy the owner of each building shall pay the water bill at the end of each quarter. Meter readings are taken monthly, and if there is a large increase in the consumption of water in a building this fact is brought to the attention of the owner.

The volume of water used for irrigation is relatively small due to the absence of lawns, truck gardens, and flower gardens in the old and most densely populated sections of Panama City and Colon. The new houses, built in the suburbs during the last eight years, have lawns and gardens which are watered during the four dry months of the year. The volume of water used for irrigation will gradually increase in future years as the suburbs are built up.

On the other hand, there are certain conditions which tend to increase the consumption of water as compared to that in other cities with similar climatic conditions. More baths are taken, because more shower baths are

available for the poorer class of people. More water is used for washing automobiles, because there is a greater number in use, as the first cost is lower, and there are no rivers nearby in which to wash them. There are a greater number of plumbing fixtures in the older houses than in many other cities, because there is an adequate supply of water, and because sewerage systems were installed by the Panama Canal during the first part of the construction period of the Canal and have been extended as required. Furthermore, there are certain sanitary regulations which are enforced by the health officers who are North Americans appointed by the Governor of the Panama Canal. The promoters of suburban developments are required to lay water mains and sewers before any lots may be sold. The sewers are flushed systematically.

The author is of the opinion that the brakes upon the per capita consumption of water in Panama City and Colon are the meters and the price of water.

Comparison of Consumption through Metered Services in Panama and Flat Rate Services in the Canal Zone. There is a remarkable contrast between the per capita consumption of water in Panama City and Colon, 100-per cent. metered, and in the adjoining communities in the Canal Zone with flat rates, although the climatic conditions in both districts are the same. During 1918, studies were made of the per capita consumption of water by the employees of the Panama Canal, and the following paragraphs are quoted from a paper by R. C. Hardman.[13] At that time water was supplied to employees free of charge.

> In an attempt to ascertain how much of the consumption was for strictly domestic uses and how much for industrial and irrigation, a number of family and bachelor quarters were metered in the Canal Zone. The results were at variance, ranging from 72 to 302 gal. for family quarters, with an average of 161, so that no dependence could be placed upon them. A female bachelor building showed 446 gal., and male bachelors but 241 gal. The per capita consumption of all individual quarters metered showed an average of 278 gal., which checks very closely with the 288 gal. mentioned in the preceding paragraph.
>
> The results of the study are that the average consumption for all purposes on the Canal Zone is about 400 gal., that for American domestic use is 300 gals.; and that for West Indian employees is 100 gal. for the purpose of estimating. The reasons for the high consumption are (1) the water is free and unmetered; (2) the tropical climate; and (3) the facilities for bathing freely and often.

Measurements of the consumption were taken at a later date within isolated sections of the Canal Zone communities at the Pacific end of the Canal, and it was found that the domestic per capita consumption averaged about 175 g.p.d. It is doubtful if it exceeds 200 g.p.d. per capita unless there is excessive underground leakage or a large amount of water is used for watering lawns and plants around the houses. The average per capita consumption for all purposes probably approaches 250 g.p.d.

The monthly flat rates for water now in force in the Canal Zone vary from $1.25 to $2.00 depending upon the type of house, with the number of

fixtures increasing as the water rate increases. In an old style cottage of six rooms there are two bathrooms, each with shower, water closet, and wash bowl, two faucets for the kitchen sink, two faucets for each of the two laundry tubs, and one outside faucet for a hose. The monthly flat rate for such a house is $1.25 with no restrictions placed on the use of water. The author estimates that the water used by a family of three, with a laundress in the house during two days of each week, which costs $1.25 per month in the Canal Zone, costs between $3.00 and $4.00 per month in Panama City, equal care being taken in each community to prevent leakage and waste.

The conditions which tend to increase the consumption of water in the Canal Zone as compared to those in Panama City and Colon, aside from the flat rate, are the following: the generous watering of lawns, flowers, and shrubs; prolonged and numerous shower baths; the greater number of clothes washed; more water used in general cleaning; more water used in washing automobiles; and more leakage and waste from fixtures.

Consumption of Water in Spanish-American Cities. The author is of the opinion that the reported per capita consumption of water in cities in one or more of the Central and South American countries should be used with great caution, and only with a thorough understanding of local conditions, as a base for fixing the per capita consumption of new water supplies in any one of the countries within the tropics. There are marked differences in the various countries and cities with respect to the characteristics of the people, the conditions of administration by municipal or national government, standards of living, industrial development, and climate. In general, an extremely low per capita consumption of water may be regarded as an indication of unusual local conditions.

The following conditions tend to restrict the consumption of water in Spanish American cities. The supply is frequently inadequate, and the pressure is too low to distribute the water through the houses and buildings. The per capita consumption may be 25 g.p.d. or less during the months in which the greatest amount of water is available and 10 g.p.d. or less during the dry months due to necessary conservation.

The poor people can not afford service connections, and oftentimes there are no mains in the streets on which they live. The municipality generally furnishes water free to the poor people from public hydrants, and they carry it to their homes in various sorts of containers so that their per capita consumption is small. In some cities there are springs from which some of the poor people carry water.

In the better class of houses in many of the municipalities, there is only one bathroom and one water closet, if any. In many cases, there are no sewerage systems and only a few scattered sewers on some of the principal streets. The author knows of one old city, with a population of approximately 100 000, in which water closets are installed in not more than 100 houses. One room is set aside in the majority of houses to be used by

the members of the family as a privy. Once a week a man comes to clean out the fecal matter that has accumulated on the floor and to use this material as a supply of fertilizer for his farm.

The city may be divided into districts to which water is supplied only during two to three hours during the day. The distribution system may not cover the entire city, thus reducing consumption of water and leakage. Low pressure and a small number of fixtures reduce the amount of water wasted. In a few cities, where the per capita consumption approaches 90 g.p.d., the system is unmetered, and there is both willful waste of water by consumers and excessive underground leakage from the distribution system. As a result of low pressure in some sections of the city, due to an inadequate supply of water, the houses are supplied with a small tank set in the ground into which the service pipe discharges. A float valve is

TABLE 3.— PER CAPITA CONSUMPTION OF WATER IN THIRTEEN CITIES WITHIN THE TROPICS.

City.	Volume per 24 Hours. Gallons.	Liters.
Barranquilla, Colombia	43[1]	163
	51[2]	193
Bogota, Colombia	56[3]	212
Buenaventura, Colombia	66[4]	250
Cali, Colombia	53[5]	200
	44[6]	177
Caracas, Venezuela	53[7]	200
Colon, Panama	73[8]	276
Guayaquil, Ecuador	48	182
Lima, Peru, and Suburbs	87[9]	330
	66[10]	250
Managua, Nicaragua	50[11]	189
Medellin, Colombia	79[12]	300
Panama City, Panama	60[13]	227
	50[14]	189
San Jose, Costa Rica	120[15]	454
San Salvador, El Salvador	39[16]	148

[1]Average daily consumption during 1933 divided by population of 140 000; 18 public fountains in service for supplying water to poor families; about 74 per cent. of services in use; no metered services.
[2]Per capita consumption in April, 1934, near end of an unusually long and severe dry season.
[3]Based on consumption by metered consumers with water entering distribution system 24 hours per day; 20.8 per cent. of services metered at end of 1933.
[4]Per capita consumption as estimated by designers of new water supply system in 1932 with meters on services.
[5]Average daily consumption in August, 1935, divided by estimated population of 100 000.
[6]Estimated consumption by people supplied through meters.
[7]Estimated by Thorndike Saville (Reference 14 in bibliography).
[8]Average daily consumption during year ended June 30, 1935, divided by population of 30 000; services 100 per cent. metered.
[9]Average daily volume of water in January, 1933, divided by estimated population supplied by water supply system.
[10]Adopted by Sir Douglas Fox & Partners, London, in report to municipality in 1915, as basis for improving the water supply system.
[11]Adopted by designers of new water supply system in 1932.
[12]Estimated in 1931 with 76 per cent. of services metered and with no shortage of water.
[13]Assumed by Carleton E. Davis in 1904.
[14]Average daily consumption during year ended June 30, 1935, divided by population of 78 000; services 100 per cent. metered.
[15]Excessive waste and no meters.
[16]Metering of Services has been nearly completed.

provided for shutting off the water when the tank is full, but oftentimes the valve does not work properly, and the water runs to waste until it is shut off. Needless to say, a meter does not form part of such an installation.

In addition to waste of water, domestic consumption has increased in suburban developments. More bathrooms and fixtures are being installed in new houses. If the climate is rather cool, hot-water boilers, formerly unknown, are now being provided. The houses are not built as close together, as they were in the old sections of the city, leaving areas for lawns and flower gardens which require water. There is an increasing number of garages and automobiles, so that more water is used for washing cars. There are more parks and paved streets to increase the public use of water.

As adequate water supplies are placed in service, the use of set tubs for washing clothes at residences grows more common, and the old custom of taking the clothes to one of the nearby creeks or rivers and beating them on the rocks is being abandoned. Steam laundries are found in very few cities in the tropics.

As a result of his experience and studies, the author has drawn the following general conclusions relative to per capita consumption of water in cities within the tropics with populations of 10 000 or more: consumption does not exceed 105 g.p.d. per day; runs as high as 88 g.p.d. in some of the larger cities without meters; averages about 60 g.p.d. in cities with climatic conditions similar to those in Panama City and Colon and with the services 100-per cent. metered; and will seldom drop below 50 g.p.d. if there is an adequate supply of water under adequate pressure, if the majority of the houses are connected to the distribution system, and if 90 per cent. or more of the services are metered.

Table 3 contains figures of the per capita consumption of water in 13 cities within the tropics based upon personal knowledge, correspondence and reports.

Fire Service in the Tropics.

Statements to the effect that fire service is not required in Spanish American cities in the tropics, because buildings are fireproof, are misleading. It is true that provision had not been made for fire protection when distribution systems were first laid out and later on extended in all directions in attempts to supply water to increasing populations, but it is very doubtful that the type of building construction was adopted with this end in view. It is more probable that lack of fire protection in most of the tropical cities, prior to 1920, was due primarily to inadequacy of water supply systems and not to adoption of preventive measures to eliminate fire hazards.

With few exceptions, of which Cartegena, Colombia, is a good example, the buildings in cities on the coasts, serving as ports of entry to the various countries, were constructed almost entirely of wood until recently. Guayaquil, Ecuador, has been repeatedly burned due to the flimsy construction of its buildings, the greater fires occurring in 1707, 1764, 1865,

1896, and 1899. In Mollendo, the sea port for the department of Arequipa, Peru, the majority of houses are of wood, and destructive fires have occurred repeatedly.

Buenaventura, Colombia, and Colon and Panama City, Panama, are examples of coastal cities subject to heavy rainfall which, while reducing the fire hazards, does not eliminate the necessity of fire protection. A fire destroyed most of the business section of Buenaventura in 1931. Nearly all buildings were constructed of wood. On account of inadequate water supply, great difficulty was encountered in stopping the fire. A new water supply was placed in service in 1934 and the old distribution system revamped and extended. Post hydrants, with an outlet for 2½-in. fire hose, were set so that the distance to the nearest hydrant from any point on the distribution system did not exceed 197 ft. On the docks, a sufficient number of special hydrants with two outlets was provided for the protection of the warehouses.

Prior to 1915, nearly all buildings in Colon were constructed of wood. In 1885, nearly the whole city was destroyed, and 10 000 people were rendered homeless. This fire was set at different points by a gang of marauders and, as there was a strong wind and no water supply, the flames spread rapidly. In March, 1911, ten city blocks were burned. In May, 1915, 22 city blocks, covering an area of 19.5 acres, were burned; 430 buildings were destroyed and 7 500 people rendered homeless; five persons were killed and the property loss was $3 000 000. The new rapid sand-filtration plant was operated at a rate 25 per cent. in excess of its capacity of 8 m.g.d. to supply water to the fire pumps, and two fire-boats pumped salt water into the fire area. Five fire departments combined to fight the conflagration. In 1917, a fire destroyed a considerable number of wooden buildings. Following the 1915 fire, the erection of wooden buildings of any sort was prohibited. Since 1920, while fires have occurred, there have been none of disastrous type. This can be attributed to concrete construction, a great improvement in the fire department, and the installation of a fire-alarm telegraph system. Many wooden buildings still remain, but they are gradually being replaced by more fire resistant structures.

In 1644, a fire destroyed the majority of the buildings, including the cathedral, in Old Panama, located about 6 miles westward of the present city. Mendosa states in his history that the town consisted of 504 houses, of which 8 were of masonry and 332 of wood, the remainder being native huts. In 1671, practically the whole town was again destroyed by fire following a raid by Morgan, although it is recorded that both the inhabitants and raiders attempted to check the fire.

In Panama City, as now located, there have been numerous fires since the construction of the Panama Canal was started. From 1904 to 1914, a large number of wooden buildings was constructed. Durham[15] described two serious fires during the construction of the streets and the distribution system for the water works:

The first, probably caused by the operations of a fumigating gang, burned over several blocks in the western part of the city occupied by the poorer and most inflammable class of houses, but, as it happened at mid-day, the forces of the construction gangs were fortunately available for prompt assistance to the zealous but inadequate native fire department.

The second originated after midnight in a large lodging-house near the center of the city, and for several hours before daylight presented a serious task to prevent its spreading over the entire town. As it was, the buildings over more than two blocks in the heart of the town were completely destroyed, but in both cases a demonstration was given of the efficacy of the water supply, without which the fires might have consumed the entire city. The hydrants and ample water supply were, of course, an entire novelty to the old fashioned fire department, whose members were always punctilious about putting on their uniforms before proceeding to a fire. They selected by preference those hydrants at a safe distance from the flames, then after coupling their hose and turning on the water, proceeded to stretch lines ranging from 250 to 500 ft., crossing each other and sometimes running past unused hydrants. The ultimate extinguishing of the conflagration was usually done in spite of the department, by a large accession of volunteers from the Municipal Engineering Division forces.

So far as the author knows, the first well equipped fire department in the tropics was developed in Panama City, following the installation of the water works, and its well trained personnel has an excellent reputation for extinguishing fires. Several other cities have called the chief of the department, Juan A. Guizado, to organize similar departments, following rather large and destructive fires. For fighting fires, the pressure in the distribution system in Panama City is raised to 100 lb. per sq. in. by pumps in the Canal Zone pumping station, and there are two distribution reservoirs from which water may be taken in addition to the supply line from the Miraflores filtration plant.

There are still many wooden buildings in Panama City, but since 1915, the majority of new buildings has been constructed of concrete, hollow blocks, and stone so that they may be termed nearly fireproof. Fires still occur frequently but are usually extinguished quickly with small losses. In many cases, only chemical extinguishers are used, but if it were not for the protection afforded by the ample supply of water, which is available under adequate pressure, disastrous fires would occur.

There are many wooden houses in the Canal Zone which may be classed as very bad fire risks, especially during the dry season with a strong wind blowing, but for some reason or other fires are rare, and it is seldom that a building is destroyed. The rarity of fires in the Canal Zone, as compared with Panama City, may be due to better living conditions and freedom from accumulations of rubbish in houses, together with the fact that the occupants are naturally more careful. The author believes that many more fires would occur in the wooden houses, both in the Canal Zone and in Spanish-American cities in regions of heavy rainfall in the tropics, if it were not for the high percentage of moisture in the woodwork, papers, rugs, furniture, etc. Many times, he has seen cigarette stubs and burning matches thrown on papers and rubbish without their starting to burn. However, it is improbable that any engineer, familiar with conditions in

a city similar to Panama City, or in towns similar to those in the Canal Zone, would design a water supply system without making allowance for fire protection.

Most of the buildings in the older cities in the interior of the countries in the tropics are quite different from those in the coastal cities. The majority of houses, prior to the introduction of concrete and burned brick, were built one story high of blocks of clay, or sun-dried bricks of clay, or of cane plastered over with clay, with thatched roofs at first and later on with tile roofs. As the cities increased in size and importance, a considerable number of two-story and a few three-story buildings were erected. The second and third stories were frequently of wood framework, especially in cities subject to earthquakes. The roofs were supported by a framework of wood, and the floors, stairways, porches, balconies, and stairways were built of wood, so that the two- and three-story buildings lost the more nearly fire-proof character of the one-story buildings. The ground floors of many of the two- and three-story buildings were gradually converted into stores and offices. The blocks were entirely covered with buildings, set against each other, with the interior courtyards, known as *patios*, forming the only open areas.

Notwithstanding the so-called fire-proof character of these buildings, several large fires and many small ones have occurred in cities in the interior of tropical countries since 1920 with accompanying large losses to property owners. As a result, the inhabitants awoke to the necessity of fire protection and took steps to obtain it. For example, in Medellin, Colombia, following the destruction of several of the principal buildings in the business section of the city in 1922, a fire department was organized, equipped and trained by the retired chief of a fire department in a city in the United States. Since the department was organized, it has prevented the destruction of enough property to more than pay for the outlay in equipment and for operating expenses. Post hydrants had been included in the distribution system of the water works constructed a few years previously, but in some sections of the city the pressure was too low for fire service without pumping equipment.

In Cartagena, Colombia, three major fires have occurred since 1927; in the first two, rather large two-story buildings, containing stores and offices, were destroyed; and in the third, the only pier for this port was destroyed. An inadequate water supply was responsible for the total destruction of each structure. Previous to the first of these fires, there had been no fire of any importance during the preceding 25 years.

In 1925, about 15 city blocks in Manizales, Colombia, were destroyed by fire. Post hydrants were included in a new cast-iron distribution system that had been installed in 1921 in Cali, Colombia; about nine years later, following the occurrence of several fires, modern fire fighting equipment was purchased, and a fire department was organized and trained.

A fire department was organized and placed in service in July, 1928, at Barranquilla, Colombia. During the years 1929 to 1933, inclusive, the

number of fires ranged from 55 to 79 per year. The buildings in which fires started during 1933 were valued at 86 150 pesos, and the losses were estimated at 7 627 pesos; 16 out of 55 fires were caused by short circuits. A new water supply system was placed in service in July, 1928, and provided ample fire protection.

These details are given to show that an allowance should be made for fire service in designing new water supply systems, or in revamping old systems, even though the majority of buildings in the principal cities are of so-called fire-proof construction. As a matter of fact, while the exterior shell of a typical old house, or building, may be nearly fire-proof, there is enough wood in the interior to provide fuel for a dangerous fire. Once a fire

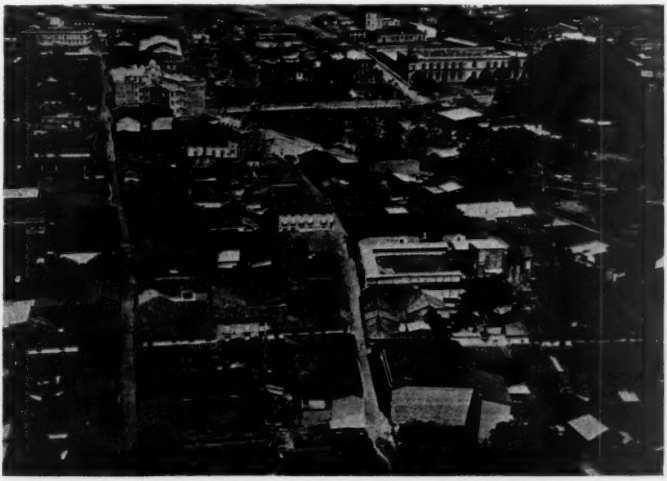

FIG. 6.— TYPICAL RESIDENTIAL SECTION IN CALI, COLOMBIA. WITH HOUSES COVERING PRACTICALLY THE ENTIRE AREA OF EACH CITY BLOCK.

The black holes in the tile roofs are the openings over the interior courtyards or patios.

starts, sparks may be carried into other buildings through the *patios*, of which there are as many as three or four in some of the larger houses, so that the tile roofs do not furnish as much protection as one may think at first sight. In many cities, especially in the older sections, the streets are narrow so that the projecting wooden porches or balconies and shutters, of old Spanish style, on a house adjoining a burning building or on one or the other side of the street, are usually set on fire. As a result, a conflagration may easily develop if hose streams are not available for fighting the fire.

Conditions relative to fire protection in the tropics may be summarized as follows: There is no doubt that the type of building construction used

in the cities in the interior of tropical countries reduces the fire hazards, but the term "fire-proof" is a misnomer. Fires have occurred more frequently during the last 15 years than in the years prior to 1920, because fire hazards have increased as the cities have grown larger and adopted modern conveniences. Larger buildings of greater height and value are being built in both the business and residential sections of cities. In designing new water supply systems for cities in the tropics, or revamping old ones, the author is of the opinion that provisions should be made for ample fire protection but on a smaller scale than that developed in North American cities, except in high-value business districts.

Water-borne Diseases.

In the tropics, the water supply engineer must reckon not only with those water-borne diseases which are prevalent in the temperate zone, such as typhoid fever, bacillary dysentery, and common diarrhea, but also with diseases caused by protozoa and parasitic worms which are more common than in the temperate zone. The part that water plays in the transmission of disease in tropical and sub-tropical countries is far more important than generally recognized in the past. As time goes on, purification of all surface supplies by filtration and disinfection will be considered absolutely essential, even if the waters are practically clear and colorless and are taken from so-called uninhabited catchment areas. While the author firmly believes in the control of quality of water supplies by bacteriological examinations, he is convinced that they may create a false sense of security in the case of unfiltered water supplies in the tropics, because they do not indicate definitely that protozoa and parasitic worms are absent. Sanitary inspections are even more important in the tropics than in the temperate zones.

There is frequently an excessive mortality from intestinal diseases classed as diarrhea and enteritis in communities in the tropics. While polluted water is only one of the causative agents in communities in which sanitary conditions are bad, it is known that the substitution of a pure water supply effects a striking reduction in the mortality rate of diarrhea and enteritis. The conditions reported[16] in the Mexican state of Yucatan furnish a good example of those prevailing in many smaller communities in the tropics.

> The observations described indicate that contaminated drinking water is the principal source of intestinal infections in the vicinity of Dzitas and of Chichen Itzá. What is true of this region is, probably, equally true for other small Yucatecan communities and for all Indian villages. The lack of modern sanitation points unmistakably to drinking water as a very serious source of danger in Merida and in other cities in Yucatan.
>
> That safe municipal water supplies are urgently needed by the cities in Yucatan is beyond question. It is believed that in the smaller Yucatecan communities and in the Indian villages much could be done to reduce the death-rate and to improve the health if the people could be taught the dangers of contaminated water, the importance

of cleanliness of water-containers and the protection offered by boiling. To prevent the contamination of wells would require a complete change in the habits of the people and the expenditure of effort and money which could hardly be expected of the general population in the near future.

A very large proportion of all deaths in Yucatan is attributable to diarrhea, enteritis, or dysentery, and a corresponding high death rate from similar causes exists in many parts of Central America. Table — gives vital statistics for the city of Merida for the years 1924 and 1925. During this period 40.2 per cent. of all deaths were attributed to diarrhea, enteritis, or dysentery; and of the deaths among children under five years of age, 58 per cent. were ascribed to one of these causes.

DEATHS IN MERIDA, YUCATAN (Population 60 000 to 75 000), DUE TO DIARRHEA, ENTERITIS AND DYSENTERY. (Adapted from Hoffman 1927).

	1924		1925	
Deaths from	Under 5 Years.	All Ages.	Under 5 Years.	All Ages.
Diarrhea and enteritis	624	1041	385	814
Dysentery	22	44	16	41
All Causes	1075	2512	735	2312

From the figures shown above, it is clear that intestinal infections represent a major health problem in Merida. Milk can at once be excluded as an important source of infection, because very little milk is used in Yucatan. Consequently, the drinking water falls at once under suspicion.

Lloyd has made the following statements concerning Schistosomiasis (Bilharziasis) one of the diseases caused by a parasitic worm and transmitted by water:[17]

This disease is not very common but occurs in the West Indies and along the northern and eastern coast regions of South America. It is caused by a very troublesome worm which will live in the body for many years, sometimes producing much suffering, though not always so. The eggs of this worm pass from the infected individual with his body wastes and hatch out in fresh water. The newly hatched embryo then enters the body of a snail, where it undergoes further development and multiplication. When the newly formed "cercariae," as they are called, escape from the body of the snail, they will penetrate the skin of man.

In order to avoid infection with these worms, one should not, in infested localities, wade or bathe in water that may be contaminated with the alvine discharges of human beings. This precaution applies to small pools and ditches, as well as to larger bodies of water. Such water, of course, should not be drunk.

Hegner has written as follows concerning this disease:[18]

Warnings should be made against drinking or bathing in canals or rivers of endemic areas. Only boiled water or water treated with sulphate-of-soda tablets should be used for drinking and water boiled or treated with lysol, creolin or cresol in solutions of 1: 10 000 for bathing. . . . Chlorine in the strength of 1: 1 000 000 appears to have no effect on the cercariae.

In Japan, prophylactic measures against Schistosomiasis have been concentrated on the eradication of the snail host, *Blanfordia nosophora*. Lime in a concentration of 0.1 per cent. has been found effective not only in killing the snail host, but in destroying the cercariae as well. It is spread thickly on the banks and in slowly running water. Chlorinated lime and copper sulphate are also efficacious against the snails but have been found detrimental to crops. . . . Reservoir hosts are eliminated as far as possible from the endemic areas and the possession of dogs and cats is discouraged. Oxen are replaced by horses, as the horse appears to acquire immunity against the disease.

Schistosoma mansoni is reported as endemic in Martinique, Guadaloupe, Porto Rico, French and Dutch Guiana, Venezuela and Northern Brazil. In the 1933 annual report of the Rockefeller Foundation, mention is made of the discharge of eggs of *Schistosoma mansoni* by 30 per cent. of 200 persons living in Rincon del Valle, a suburb of Caracas, Venezuela, and of the pollution of streams, infested by snails of the proper species, by many of these persons.

The following general measures of control of Schistosomiasis are given in a report of a committee of the American Public Health Association on "The Control of Communicable Diseases":[19]

1. Regulation of disposal of sewage. 2. Conservation of night soil long enough to sterilize ova through fermentation of medium. 3. Cleansing of banks of infested water supplies to remove snail shelters. 4. Application of lime or copper suphate to kill infested shelters. 5. Filtration of drinking water from infested sources. 6. Treatment of the infested person by tartar emetic or its derivatives. 7. Education of the people regarding spread and prevention of infestation.

Ancylostomiasis (Hookworm Disease) may be contracted by drinking water contaminated by the feces of persons who have this disease, but it is the general opinion of authorities that the usual manner of infestation is through the skin. Hookworm disease is most prevalent in the warm and moist sections of the tropics.

Ascariasis, caused by the common round worm of man, *Ascaris lumbricoides*, is most prevalent in tropical and sub-tropical countries. The following data have been taken from a discussion of this disease by Hegner:[18]

Infection with Ascaris results from ingesting eggs containing fully developed embryo. The eggs are usually carried to the mouth either with food or water or by accidental transfer of soil containing such ova. . . . The number of ascaris eggs per gram of feces passed by an infected person may average over 2 000 per female worm. . . . Because of their great longevity, the soil exposed to continual pollution may become exceedingly heavily laden with living Ascaris eggs within the course of time.

Water from questionable sources should be boiled for drinking purposes and green vegetables and fruits from gardens fertilized with human excreta avoided. Sanitation, sewer systems in cities and towns, and sanitary privies on farms, together with personal habits of cleanliness, are effective measures against Ascaris infection in man.

Of the diseases in the tropics, produced by pathogenic protozoa, the most important and widely distributed is amebiasis. Craig[20] defines the clinical term amebiasis as "the invasion of the tissues of man by the pathogenic ameba, *Endameba histolytica*," and the term amebic dysentery as "a bloody, mucoid diarrhea caused by *Endameba histolytica* and occurring as one of the manifestations of amebiasis."

Amebiasis is caused by the ingestion of food and liquids contaminated by fecal matter containing the cysts of *E. histolytica*. The stools from acute cases of amebiasis seldom contain infective cysts and are not dangerous. The stools from convalescent cases, from untreated or improperly treated cases of amebic dysentery and from cases of chronic amebiasis or carriers contain infective cysts and are potentially dangerous.

Amebiasis is an old problem in the tropics of Spanish America. It has existed in endemic form in several countries and has been more or less prevalent in the others. Little progress has been made in the adoption of measures to control its transmission, except in a few isolated colonies established by foreign capital for the production of fruit, minerals, etc.

Typhoid fever, yellow fever, hookworm and malaria have thrust amebiasis into the background in the tropics. Amebiasis has been accepted undoubtedly by the majority of persons in endemic areas as one of the afflictions they must suffer, as a matter of course, and to which they have given little thought. Many travelers in the tropics have contracted amebic dysentery and learned to respect it after taking the treatment required to regain good health. This disease still remains one of the greatest hazards to the traveler[17] in Central and South America, because progress in sanitation and personal hygiene has not kept pace with the improvements made in transportation during the last 20 years.

Amebiasis is prevalent in Honduras, Guatemala, Nicaragua, Costa Rica, Panama, Venezuela, Peru, Brazil, Argentina, and the islands of Haiti, Porto Rico, Cuba and San Domingo. This is not surprising in view of the extensive and intensive soil pollution by human excreta as a result of inadequate latrine accommodations in rural districts and lack of sewers in urban districts; abundance of flies; use of human feces as fertilizer in many districts; and lack of attention to elementary principles of hygiene by a large percentage of the population.

It is now generally recognized that amebiasis and its most serious manifestation, amebic dysentery, is not limited by the varying temperatures and altitudes encountered by the inhabitants of the tropics. Musgrave[21] wrote as follows concerning the physiography of amebiasis:

> Amebiasis is widespread and constantly present throughout the tropical and to a less extent the sub-tropical belts, where it constitutes a sanitary and health problem of the first magnitude. Sporadic infections are found in practically all countries, and the first recognized case was found in a temperate zone. Nevertheless, the home of the disease is in warm countries because of sanitary conditions and the favorable environment for the propagation of the parasites, and the decreased resistance of the residents of those countries. Statements regarding the predisposing importance of any special constituent of physiographic environment in the disease must be conservative. Humidity and excessive rainfall seem to be of importance, because the epidemiologic wave is highest about the close of the wet season.
>
> Altitude, as such, probably has nothing to do with the spread of the infection, but sudden changes from the tropical lowlands to a high altitude, or *vice versa*, certainly exert a marked influence upon the development of clinical symptoms. Latent infection becomes active under such change with striking frequency.

As the result of surveys made in the United States, it is estimated that between 5 and 10 per cent. of the population are infected with *E. histolytica*. In the tropics, a greater percentage of the population is infected with this parasite as indicated by the following data:

Table 4 gives a summary of the data obtained by Faust[22] in his study of six groups of persons living in Panama which "represent a complete

cross section of life in Panama, from the lowest to the highest economic strata, and from complete unsanitation to sanitation *par excellence* in the tropics."

TABLE 4.— INCIDENCE OF *Endameba histolytica* IN REPRESENTATIVE GROUPS IN PANAMA.

Group.	Incidence. Percentage
Native River Villages (unsanitated): A	72.7
Native River Villages (unsanitated): B	33.0
Male Medical and Surgical Services, Santo Tomas Hospital, Panama City	19.1
Female Medical and Maternity Services, Santo Tomas Hospital, Panama City	14.3
White Patients and Staff, Gorgas Hospital, Canal Zone	8.55
White Staff, Canal Zone Administration Building	2.81

In 1925, Kofoid and James[23] examined 367 persons during an investigation of intestinal protozoan infections in the hospital of the United Fruit Company at Santa Marta, Colombia, S. A. The incidence of amebiasis is shown in Table 5.

TABLE 5.— INCIDENCE OF AMEBIASIS IN THE HOSPITAL OF THE UNITED FRUIT COMPANY AT SANTA MARTA, COLOMBIA, S. A.

Group.	No. of Persons.	Percentage *Endameba dysenteriae.*
Hospital Patients	214	55.7
Hospital Personnel	81	51.9
Club Servants	13	61.5
Dr. James' Patients	17	64.7
Staff of United Fruit Co.	42	40.5

These groups are characterized as follows in the report of Kofoid[24]:

The hospital patients consist almost wholly of employees and members of their families in the Santa Marta division, with some additions from the local population of the same general types as the employees. These are largely native Colombians with some from Central America and the West Indies, especially Jamaica. They are of the mixed racial stocks of Indian, African, Carib, and Caucasian types, but form a cultural unit represented by the laboring and agricultural classes, with some predominance of the more mobile elements from these classes.

The hospital personnel, exclusive of the medical staff, consists "mainly of persons of Colombian origin with a larger increment, than among the patients, from racial mixtures involving Caucasian stocks, and from better educated groups in the case of the technical services of the hospital." The club servants consist "largely of negro West Indian stock." The patients of Dr. W. M. James "represent the educated and cultured classes, and come from homes of the highest standards of sanitation in the community." The staff of the United Fruit Company consists "principally of Americans from the United States, mainly with at least several years residence in the Tropics, and of three Colombia physicians."

Taken as a whole, the five groups represent rather fully the native population, the coastal immigrants from tropical America, and the imported American personnel.

The incidence of infection with *E. histolytica* in Haiti was reported by Williams and Thomas[20] as 50.0 per cent. in 109 domestics, and as

16.26 per cent. in 2 069 hospital cases by Williams, Wildman and Curtis.[20] De Ballard[25] reported an incidence of 30.0 per cent. for Venezuela in 1918.

Connell[25] examined 854 persons in nine localities in the Mexican state of Yucatan and found that 166, or 19.5 per cent. were infected with *E. histolytica*: "Twenty-eight of those infected, or 3.3 per cent. of all persons examined, had active dysentery which was evidenced by the presence of blood and mucus in the stool at the time of examination." Connell estimated that the true incidence of *E. histolytica* (carriers and active dysentery) in the general population at about 40 per cent.

A difference of opinion prevails among protozoölogists, physicians, and public health workers as to the extent to which amebiasis is transmitted by water in the tropics. Some believe that infected food is a more active agent in its distribution than a polluted water supply, while others believe that direct personal contact with infected feces is the principal method of transmission. It is generally agreed that carriers are important agents in the distribution of the disease. Flies must also be given consideration.

It is obvious that the viability of the cysts of *E. histolytica* in feces, as deposited in privies and on the ground, in mixtures of feces and water and in streams and bodies of water is an important factor in the transmission of amebiasis from one person to another. Laboratory experiments by several parties have indicated that the cysts will live in moist feces at room temperature, 10 to 20°C., from 3 to 7 days; in water at room temperature, the majority will live 14 to 21 days and some will live 37 days; if kept in water at 7°C., some will survive for 46 days, but at body temperature they will usually die within 3 days; if exposed to temperatures of 0 to 5°C., they will survive about 48 hours; and if subjected to drying in the air at room temperature, they will not survive longer than 5 to 10 minutes.

Based on these data, it appears reasonable to draw the following conclusions: (1) That cysts in feces deposited on a watershed during a dry season and exposed to bright tropical sunlight will be killed ordinarily before the feces are conveyed to the nearest surface stream by the first rainfall; (2) that cysts in feces deposited on a watershed subjected to rains on 25 days or more of each month will be conveyed to a surface stream while they are still alive; (3) that cysts in feces deposited on watersheds at high altitudes, with an air temperature of 0 to 5°C. during the night and rising to 7 to 12°C. during the day, and with little or no sunlight, will survive for at least 48 hours and will reach a surface stream uninjured if rain falls within this period, but that if rain does not fall within 48 hours, the cysts will probably die.

Assuming that live cysts are carried into a surface stream by the run-off from a watershed, it appears reasonable to assume that many of them will live for 21 days, if the temperature ranges between 7 to 10°C.; for 14 days, if the temperature ranges between 10 to 22°C.; and for at least 7 days, if the temperature ranges between 27 to 30°C.; and that only a few will live for 3 days, if the temperature rises to 37.5°C.

The majority of the rivers from which water supplies are taken in the tropics are small, swift-running streams. The run-off from rain on any part of the watershed will reach the intake of a water works within 12 to 24 hours and will be distributed throughout the distribution system within 12 hours at the most. Therefore, the period of time during which the cysts must live in a surface stream could be reduced to 36 hours, from the periods given in the preceding paragraph, so that there is little doubt that they will reach the consumers in good condition assuming, of course, that the water is not filtered.

In some of the smaller communities, the water supply, derived either from springs or surface streams, is distributed by gravity through small open canals in the streets and is dipped out of them by the inhabitants. A water supply distributed in this manner is certain to be an active agent in the transmission of cysts of *E. histolytica* and parasitic worms, in addition to pathogenic bacteria, because the water flowing through each one of the canals is polluted by fecal matter from each house it passes. The slops thrown upon the heavily polluted ground in the *patios* drain into the canals, and during rains the surface drainage sweeps the accumulated excreta from the ground around the houses into the canals. By the time the water reaches the houses in the lower sections of a town, it is converted into a dilute sewage.

Water flowing through irrigation ditches, polluted by washings from cultivated tracts fertilized with human excreta, and by the excreta from laborers on farms, is frequently used by the people living and working on the farms. There can be no doubt that irrigation water is an active agent in the transmission of cysts of *E. histolytica*.

If the water supply passes through an impounding reservoir, there is little doubt that many of the cysts will settle rather quickly to the bottom, as they are heavier than water and their volume is 400 to 900 times that of the typhoid bacillus. If the conditions are such that the sediment on the bottom of the reservoir remains undisturbed, or is not pulled into the outlet pipe, the cysts will remain in the sediment and perish. When the water flowing into the reservoir is muddy, the settling rate of the cysts will be increased by the added weight of the adhering particles of clay.

In the case of a large and long river with a relatively small population on the watershed, it appears to be reasonable to assume that dilution, sedimentation and prolonged exposure in the water will eliminate the cysts or reduce them to such a small number that the unfiltered water will not infect the consumers with amebiasis.

It is reasonably certain that a water supply taken from a small river, into which fecal matter is carried by every rain on the watershed, as described under the San Francisco river in Bogota, Colombia, and conveyed to the consumers without filtration, or preliminary storage, is an active agent in the transmission of amebiasis. With a sufficient number of feces deposited by carriers or convalescent cases attending the Monserrate

Church on a Sunday, a rainfall within the following 48 hours of sufficient intensity to carry the greater part of the feces down a steep slope into the nearest tributary of the San Francisco River, a flow of one hour or less in a swift running stream to carry the cysts to the intake in the river proper, followed by their immediate entrance into the distribution system, there is a perfect set-up for the development of amebic dysentery among a portion of the consumers.

To give a better idea of the concentration of cysts which may exist in the San Francisco River, the following hypothetical case is presented. Assume that the percentage incidence of *E. histolytica* among the 2 000

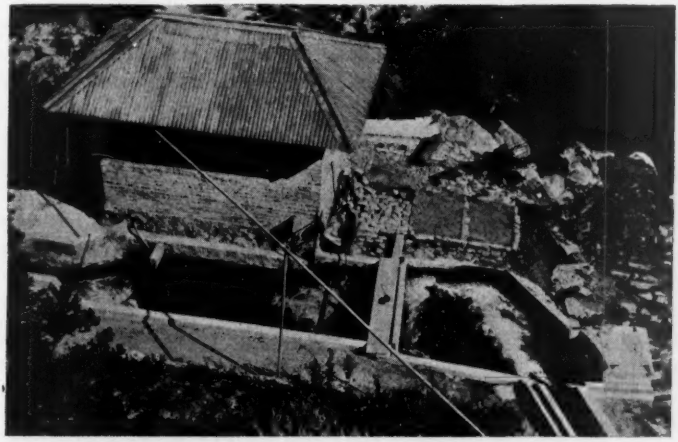

FIG. 7.— SAN FRANCISCO RIVER WATER SUPPLY, BOGOTA, COLOMBIA, S. A.

The intake channel is at the lower right; progressing toward the left are the grit chamber, a screen of copper mosquito mesh to remove leaves, the chlorine house, the measuring weir and the entrance to the distribution system. Chlorine is added through a perforated pipe back of the weir.

visitors to the Monserrate church on a Sunday is 30, a conservative allowance;—on this basis 600 persons will discharge cysts in their stools;—assume that of the 600 persons only 10 per cent., or 60, defecate on the ground near the church; assume that each stool contains 200 000 000 cysts and that half of the feces, or 30, are washed into the river by a rainfall lasting 2 hours; assume that the flow of the river is 182 liters per second and that all of the water enters the distribution system (in accordance with personal observation and measurement); then the water entering the distribution system will contain an average of 4 660 cysts per liter during a period of 2 hours, or 933 cysts in an ordinary drinking glass of 200 ml.

The number of persons who would be infected with amebiasis depends upon the number that drink water during the assumed period of 2 hours,

or draw water from the mains to be used later, and this in turn depends upon the area covered by the distribution system, the volume of water consumed per hour, etc. It is probable that a large proportion of the consumers would not be infected, since the number of cysts per liter would decrease as the infected water mixed with the uninfected water in the distribution system. The number of persons who would be infected also depends upon their susceptibility and immunity.

While this, of course, is a hypothetical case, based only upon a known flow of water, the topography of the watershed, and the attendance at the church, the author is convinced that it demonstrates that amebiasis must be considered as a water-borne disease. This case is exceptional only in regard to the origin of the pollution; it is not exceptional so far as the pollution of a small river in the tropics by sewage is concerned. Amebic dysentery has been prevalent in Bogota for many years, but unfortunately the author has been unable to secure reliable statistics of mortality in time to include them in this paper.

In the many small communities in which the soil is polluted constantly by the excreta of the inhabitants, the small storage ponds for catching surface run-off, the water holes in the beds of small streams, and the shallow dug wells, all must be subject to continuous infection by cysts of *E. histolytica*, and likewise the containers in which water is carried. In such communities, polluted water, finger to mouth infection, food and flies are active in maintaining a vicious circle of transmission of the cysts among the inhabitants. If it were possible to substitute filtered water for the polluted water supplies in these communities, a reduction in the number of cases of amebiasis would undoubtedly follow, but the disease would continue to exist due to direct transmission of cysts from feces to fingers, fingers to mouth, fingers to food and thence to mouth, and by fly droppings on food. To effect a further reduction in the incidence of infection, it would be necessary to remove the human excreta from each house by the water-carriage system and to dispose of the combined sewage in such a way as to prevent the production of a nuisance and to obviate danger to the health of the community.

The opinion of some physicians, public health workers and others that contaminated water is not an active agent in the transmission of amebiasis as is infected food, or the finger-to-mouth transfer of feces, appears to be based on the supposition that a larger number of cysts are infested through the two latter modes of transmission. Without going into details as to what may happen to decrease the number of cysts on fingers, soiled with feces, before they reach the mouth, directly or indirectly, the author has reached the conclusion that water supplies, polluted as they are in the tropics, are equally important as a mode of transmission of amebiasis as other agents, and in some cases more important.

The Chicago epidemic in 1933 threw the spot-light of publicity upon amebic dysentery as a water-borne disease. The contamination of drinking

water in hotels, restaurants and in industrial plants by sewage through cross-connections or faulty plumbing has been emphasized strongly in the literature published relative to this epidemic, but little attention has been given to the continuous or intermittent contamination of surface water supplies by the cysts of *Endameba histolytica*. In the tropics, at the present time, and during past years, pollution of water by feces deposited on the catchment areas of surface water supplies is the problem that requires attention rather than pollution through cross-connections.

As previously stated, this disease in the tropics has been thrust into the background by other diseases, of seemingly greater importance, with the results that statistics and epidemiological and laboratory investigations relating to amebiasis are lacking. However, there is available some circumstantial evidence, in addition to the opinions of those who have made a study of amebiasis during many years, that supports the opinion of the author that water polluted by sewage must be considered an active agent in the transmission of amebiasis in the tropics.

The first case refers to amebic dysentery on a banana plantation of the United Fruit Company[26] in Colombia, S. A., during 1928:

> Of these cases, 123 originated in the Colombia Division in 1928, as compared to 302 in 1926, and 156 in 1927. This lowered incidence is believed to be directly attributable to the improved drinking water supply. The plantation is irrigated, and the laborers use the ditches for laundry purposes; formerly they used the same ditches for their drinking-water supply, also. About three years ago, wells were driven, throughout the division, and pumps were provided. The prejudice against the use of well-water by laborers is slowly being overcome, and there is a corresponding decrease in the incidence of the disease.

The second case is the most conspicuous example in the literature on the subject of a decrease in the incidence of amebiasis following a change in water supply. Dr. Herbert C. Clark, Director of the Gorgas Memorial Laboratory in Panama City, compiled certain data relative to autopsies made in the Board of Health Laboratory of the Panama Canal from 1905 to 1923, inclusive. A very sudden decline in the number of cases of amebiasis occurred after 1914. In his discussion of the factors which aided in producing the decline in the mortality rate of this disease, Dr. Clark made the following statement:[27]

> Prior to the installation of the water systems, 1914–1915, there were 4 000 autopsies, which yielded 170 cases of amebiasis (4.25 per cent.). After this installation, there were only 2 800 autopsies, which yielded as few as 16 cases, or 0.57 per cent.

The installation of the water systems refers to the modern rapid sand-filtration plants for supplying filtered and disinfected water to Cristobal and Colon at the Atlantic end of the Panama Canal and to the population at the Pacific end, including Panama City. These systems were placed in operation in February, 1914, and March, 1915, respectively. The author believes that a discussion of the conditions existing prior to 1914–1915 will give a clearer understanding of the significance of this case.

The inhabitants of the district at the Pacific end of the canal were furnished with water obtained from the Rio Grande Reservoir and passed through pressure filters when work was first started on the canal. As the consumption of water increased both for construction and for domestic purposes, additional water was pumped into the supply main to the filtration plant from Cocoli River, near the Miraflores Locks, and later from an arm of Miraflores Lake. It is improbable that enough cysts of *E. histolytica* passed through these filters to infect the consumers of the water supply in the above communities.

The water supply for towns at Pedro Miguel and Corozal was also taken from the same sources but was not filtered and was not chlorinated until 1914. The watershed of the Rio Grande Reservoir was uninhabited, and the only persons allowed on it were the men in the gang that cut the grass around the shore line and along the feeders discharging into the reservoir. They were provided with sanitary buckets for their excreta, and at the end of each day the buckets were emptied into pits outside the watershed. Distilled water was furnished for drinking water to the houses in Pedro Miguel and Corozal.

In 1906 and 1907, small impounding reservoirs, with uninhabited watersheds, were constructed for the towns of Culebra, Empire and Gorgona where most of the men lived who worked on the construction of Gaillard Cut (then known as Culebra Cut). As the work expanded, the water supply became inadequate, and the deficiency was made up by pumping from the Chagres River at Gamboa. As it was considered that the river water contaminated the reservoir waters, with which it mixed in the distribution system, plants for distilling water were established at several points, and distilled water was delivered by carts to the houses.

It is the opinion of the author that the consumption of water from this distribution system, contaminated by Chagres River water, by the men engaged in the construction of this section of the canal was responsible for a large proportion of the cases of amebiasis found by Clark prior to 1914. Furthermore it is quite reasonable to assume that the distilled water, or water from the distribution system, in many of the numerous buckets and coolers scattered over the construction area and used in the restaurants, was infected by men who handled the water and ice.

From 1906 to 1908, the water supply for Gatun, where the dam for Gatun Lake and a set of locks were constructed, was pumped directly from the Chagres River into the distribution system without any purification. In 1908, water taken from an impounding reservoir was substituted for the Chagres River supply. The watershed of the reservoir was uninhabited and was maintained in the same manner as previously described. In December, 1911, a rapid sand-filtration plant was added to the system so that following this date it is improbable that the water supply was infected with cysts of *E. histolytica*. However, it is reasonable to assume that from 1906–1908

cases of amebiasis were contracted from the raw Chagres River water and after that from infected water buckets and coolers.

Starting in 1905, the water supply at the Atlantic end of the canal was taken from an impounding reservoir, with an uninhabited watershed, and passed through rapid sand pressure-filters so that it is improbable that the water was infected with the cysts of *E. histolytica* as it entered the distribution system. However, many of the men who lived in Cristobal and Colon worked on jobs at Gatun and other points and drank water from other sources.

Carriers undoubtedly existed among the working force. The force increased from approximately 1 000 in May, 1904, to 39 000 in 1907. From

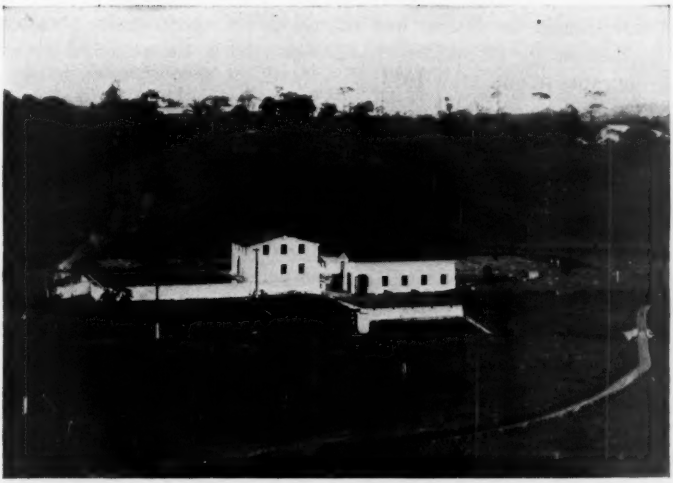

FIG. 8.— AGUA CLARA RAPID SAND-FILTRATION PLANT AT GATUN, PANAMA CANAL ZONE. NOMINAL CAPACITY, 3.3 M.G.D.

1907, it increased to a maximum of nearly 57 000 in 1913 and then declined to about 44 000 in 1914 and to 35 000 in 1915. In the force of skilled labor, there were men from the United States, Mexico, Central and South America, Cuba, Porto Rico and the Philippines. From 1904 to 1913, inclusive, a total of 45 000 unskilled laborers was brought to the Isthmus. Of these, nearly 70 per cent. came from the West Indies; 26 per cent. from Europe; and the remainder from Central and South America.

On the completion of the major construction program and the opening of the canal in 1914, the working force was gradually reduced and moved to the permanent town sites, with the result that filtered and chlorinated water was available not only in the houses but also on the majority of construction jobs. It is believed that the change, within a period of one

year,— February, 1914, to March, 1915,— to filtered water from water supplies drawn from various sources, some of which were exposed to sewage pollution, with the elimination of a large number of water buckets and coolers, was responsible for the decrease in the number of cases of amebiasis observed in the period between 1914 and 1923.

It may be argued that food infection was responsible for the transmission of amebiasis prior to 1914, but if so, the decline in the mortality rate would not have been so marked, because the restaurants operated by the Panama Canal continued to serve a large number of employees after the modern filtration plants were placed in operation. A relatively large number of colored women from the West Indies have been and are still employed in the homes of the employees of the Panama Canal as cooks and maids, but the reduction in the number of cases of amebiasis indicates that food infection in the homes was not an active agent in the transmission of this disease, for no sudden change occurred in the personal hygiene of these servants in and after 1914.

Flies may be ruled out as an active agent prior to 1914, as the sanitary measures then in force eliminated them. Garbage cans were emptied daily and the contents burned. Stable manure was disposed of so that it was not a source of fly breeding. Kitchens and restaurants were screened to keep out flies, and traps were used for catching any that entered by the doors.

In all permanent towns and semi-permanent camps, the sewage was disposed of by water carriage. In temporary camps, either fly-proof or pail closets were installed and regularly treated with crude oil or larvicide.

The third case relating to the transmission of amebiasis by water is the following as cited by Hegner:[28]

> Many of the missionaries living in the Friends Mission in Chiquimula (Guatemala) have during the past decade come down with severe attacks of amebic dysentery. About a year ago a well was drilled and a tank and oil-driven pump installed. Pipes were laid to 3 or 4 mission buildings and a pure water supply thus assured. Since then no cases of amebic dysentery have developed. In June, 1933, I examined by smear one sample from each of 7 missionaries and 47 servants, working in the mission, and children, most of whom were living in the mission. No infections with *E. histolytica* were found among the 7 missionaries and only 5 among the 47 servants and children. No survey had been made before the pure water supply was installed, hence no comparison can be drawn between conditions before and after, but the data available indicate that the water supply in former years, which is known to have been much polluted, was responsible for the transmission of some of the infections.

In reference to the relation between the water supply and amebiasis in Fresnillo, Zacatecas, Mexico, Andrews[29] made the following statement:

> The role of the water supply in the epidemiology of amebiasis in Fresnillo is difficult to evaluate. There is no reasonable doubt but that the cysts of parasitic protozoa find their way into the wells which supply most of the water for domestic purposes. This pollution is from the surface as there are few if any pit privies or similar means of disposing of human ordure other than depositing it upon the ground. During summer months when most of the rain falls, the surface drainage must carry considerable quantities of human feces into the wells, and it is significant that the reported maximum

incidence of dysentery coincides with and follows this season. As far as can be ascertained, reliable reports of the finding of *E. histolytica* in water systems have not yet been published, though there is good evidence that cysts may live in water for considerable lengths of time (Yorke and Adams, 1926, Dobell, 1927). Efforts were made to identify cysts of this organism in several samples of sediment from water reservoirs and wells. In every instance, with the single exception of the material from the tank supplying the water to the foreign residents, tremendous numbers of free-living protozoa were present but no *E. histolytica* cysts were found. . . . It is evident that in Fresnillo cysts of *E. histolytica* may get into the water supply of the native population and unless some mechanical, chemical, or biological factor interferes, infective cysts may be carried to other individuals.

Musgrave[21] expressed the following opinion concerning the method of transmission of amebiasis:

Recent work by protozoölogists seems to indicate that the principal method of transmission is more or less directly from the infected person to the healthy and that our former incrimination of uncooked food and bad water is a minor factor in the spread of the disease. Experienced sanitarians and clinicians in the tropics, without entirely discrediting such conclusions, nevertheless will put them into practice very slowly. This will be true especially of physicians who have traced a considerable number of cases of the disease developing almost simultaneously to eating lettuce from one garden or after drinking water from a common cistern.

Public health measures consist in guarding the purity of drinking water supplies, sale of foods to be eaten raw, the care and disposal of sewage and the control of pet animals, carriers and infected persons. Most of the recent work on amebas tends to minimize the importance of water, food, etc., in the spread of the disease and some authors recommend disregarding public measures for prevention entirely. This should not be done. Local epidemic flurries may at times be traced to an infected water or food supply with as much certainty as typhoid fever may be traced to similar sources. Physicians practicing in the tropics where food and water are so extensively handled by ignorant, dirty and often infected persons will do well to advise against the eating and drinking of food and water from unknown sources.

Craig[20] has written as follows concerning infection by a contaminated water supply:

Infection through the means of a contaminated water supply is a common method in localities where there is no properly impounded general water supply, for it has been shown by numerous investigators that the cysts of *Endameba histolytica* may remain viable in water for several weeks. This method of infection is important in communities that derive their water from wells and springs, where soil pollution is common, but is of little or no importance in any locality where there is a properly guarded water supply. Thus, in rural communities where the inhabitants depend for their water upon wells or springs situated near the house, and where the soil is polluted with feces, the water is almost sure to be contaminated by the cysts and this method of transmission becomes important. The severe outbreaks of amebic dysentery occurring among American troops serving in the field during the Philippine Insurrection were, without doubt, largely caused by the constant use of badly contaminated water, and the author has observed three cases of amebic dysentery in which the infection was transmitted by drinking water from a water cooler that was cared for by a "carrier" of *Endameba histolytica*.

In regard to the epidemic occurrence of amebic dysentery Craig expressed the following opinion:[30]

While under ordinary conditions the symptom complex of amebiasis known as amebic dysentery usually occurs in the form of sporadic cases, it may occur in epidemic

form if conditions as regards lowered resistance or massive dosage of cysts are present. The epidemic occurrence of amebic dysentery was observed repeatedly among troops operating in the field in the Philippines, when resistance was lowered by the conditions present in active field operations and constant reinfection by swallowing numerous cysts in highly polluted water occurred. The recent outbreak of amebic dysentery contracted in certain hotels in Chicago is another instance of the epidemic occurrence of this condition when massive infection is possible. However, it is most unusual to encounter epidemics of this type of dysentery, and it is well to remember that the vast majority of cases of amebic dysentery occurs sporadically and in this feature differ from bacillary dysentery which very frequently occurs in epidemic form.

Dr. Bolivar J. Lloyd, Medical Director, U. S. Public Health Service, in giving precautions to be observed by travelers in the Americas made the following statements:[17]

Perhaps the most frequent source of amebic dysentery is drinking water which is contaminated with the alvine discharges of human beings. . . . If water is not safe, it should be boiled for five minutes. . . . Water for bathing and for other domestic uses should be boiled as well, if regarded as unsafe.

As previously pointed out, the incidence of amebiasis in the tropics is high. On the other hand the incidence of amebic dysentery is often low which appears to indicate, as Craig has stated,[20] that:

In some regions it would appear that continued reinfection has brought about considerable resistance to the parasite as the natives apparently have a very low incidence of amebic dysentery although amebiasis is so widespread among them.

Musgrave held the following opinion in regard to immunity:[21]

The relative mildness of the disease and the large number of ameba carriers without symptoms among natives of the tropics indicate a certain amount of immunity on the part of these people or the existence of some other factor of protection for which we have no explanation.

While a difference of opinion exists as to the extent that water transmits amebiasis in comparison with other agents, it is certain that the drinking of water containing a relatively large number of cysts of *E. histolytica* by the inhabitants of a community will result in the development of amebiasis in some of them. It has been established beyond doubt that chlorine as applied in the treatment of water does not destroy cysts of *E. histolytica*. The conclusion may be drawn, therefore, that only chlorination of a water supply taken from a surface stream, polluted by sewage from a watershed on which there are habitations without privies, or over which there is an unrestrained movement of people, will not destroy cysts of *E. histolytica* and render the water safe to drink, even though the standard bacteriological examinations show that it is safe. However, it has also been established beyond doubt that filtration of water through rapid sand-filters removes the cysts.

To sum up the situation in the tropics relative to the transmission of amebiasis by polluted water supplies, the author believes that filtration is a more practical measure of control than measures designed to obtain the sanitary disposal of human feces and to prevent the pollution of catchment

areas, as he feels that little progress will be made in enforcing the two latter measures of control in the immediate future. For the communities in which it is not practical to install filtration plants, he recommends drilled wells, or springs, properly protected against contamination by surface drainage and by the people who withdraw water.

Cases of Asiatic cholera have rarely occurred in the tropics during recent years. While yellow fever is not a water-borne disease, an adequate public supply of potable water, with a service pipe to each building, has proved to be almost indispensable in combating it in endemic zones in order to eliminate the storage of water in cisterns, barrels, clay jars, and other receptacles in which mosquitoes breed.

Treatment of Water Supplies.

Chlorination. Where is the line to be drawn between the filtration of a water supply or treatment by chlorination only? From a public health standpoint, the method of treatment is of importance: (1) because the incidence of infection of the inhabitants in the tropics with *E. histolytica* is much higher, in general, than in the United States, and presumably the percentage of carriers, also; and (2) because chlorination will destroy only pathogenic organisms of the bacterial type, such as typhoid fever, cholera, dysentery, etc. and will leave unharmed the cysts of *E. histolytica.* From what may be considered as a more practical standpoint, by many, the majority of the municipalities does not have sufficient funds to construct filtration plants while they can manage to install chlorinators.

The author is of the opinion that every surface water supply in the tropics, even though it may possess satisfactory physical characteristics, should be filtered and chlorinated in order to furnish the consumers with water free from pathogenic bacteria, protozoa and parasitic worms. As previously stated, he has never yet seen a drainage area in the tropics, large or small, that was free from fecal pollution deposited either by people living on it or traveling over it, not to mention animals of various kinds. Unfortunately this opinion can be considered only as founded upon unattainable perfection under prevailing conditions and probably for some time in the future.

Purification by storage in impounding reservoirs, followed by chlorination, will not help much in solving the problem, except in a few scattered cases, on account of the large expenditure of money required. The purchase of watersheds with the removal of all habitations, public roads and trails, and the prevention of trespassing, may be rejected as impractical measures in the tropics.

In a small proportion of the municipalities that are of the greatest importance, such as capitals, seaports, and industrial centers, funds may be secured for filtration plants but often only after protracted delays. Funds for filtration plants in some of the more important and influential

cities of 10 000 to 50 000 population may be secured if the expenditures involved are relatively small. In the majority of municipalities the lack of sufficient funds throws a filtration plant out of consideration and leaves only chlorination to be considered.

The author has always recommended the chlorination of surface water supplies to serve as a temporary and partial measure of relief, especially where typhoid fever, bacillary dysentery and diarrhea are prevalent with intermittent outbreaks of an epidemic type, until such time as the funds are available for constructing a filtration plant. It is only rarely that the program for financing and constructing a filtration plant, or an entire new system of water supply, proceeds to a conclusion, or even starts, without long delays. Seldom do the parties in charge of the program have sufficient power and ability to secure the necessary money to overcome the obstacles and criticisms that are always arising and to carry the work to a successful conclusion in a relatively short time.

Most of the water supplies taken from surface streams carry considerable amounts of color, organic matter, and turbidity during the rainy months, and at times, following heavy rainfalls, the latter rises to 5 000 p.p.m. or more. The question is often raised as to the efficiency of chlorination under such conditions. The author considers that it is more practical and helpful to recommend a process that experience has shown will immediately make the water safer for use,— by killing most of the pathogenic bacteria in it,— even though it is not the ideal process of purification, than it is simply to recommend a filtration plant, when it is known that several years, even a decade, will elapse before funds will be available for building it. The author believes that one is justified in taking such a position, because many lives will be saved by chlorination, even though it is certain that not all of the pathogenic organisms will be killed by chlorination of the supply.

It is advisable, in dealing with a municipality or government, to make it clear that chlorination kills only the organisms of some of the intestinal diseases transmitted by water and does not protect consumers against amebic dysentery and parasitic worms. While such a condition is unfortunate, it is one for which no remedy exists at the present time, but there is a possibility that a method of chemical treatment to destroy the cysts of *E. histolytica* will be developed as a result of the interest that has been aroused recently in amebic dysentery in the United States.

As an example of the delay that occurs in the installation of purification plants for the water supply of cities and of the results that may be obtained by chlorination of water supplies taken from surface streams, at times clear and at other times muddy, we may take the case of Bogota, the capital of Colombia, with a population of 280 000. After making an investigation of the group of five water supplies in service in July, 1920, the author recommended the installation of duplicate chlorinators at each supply as a temporary remedial measure until such time as comprehensive studies would

determine how an adequate water supply for the city could be obtained and purified by filtration.

Chlorination of the water supplies was started near the end of 1921 and has been continued without interruption, with the exception of short intervals during the first few years when shortages occurred in the supply of chlorine due to lack of a sufficient number of cylinders to take care of

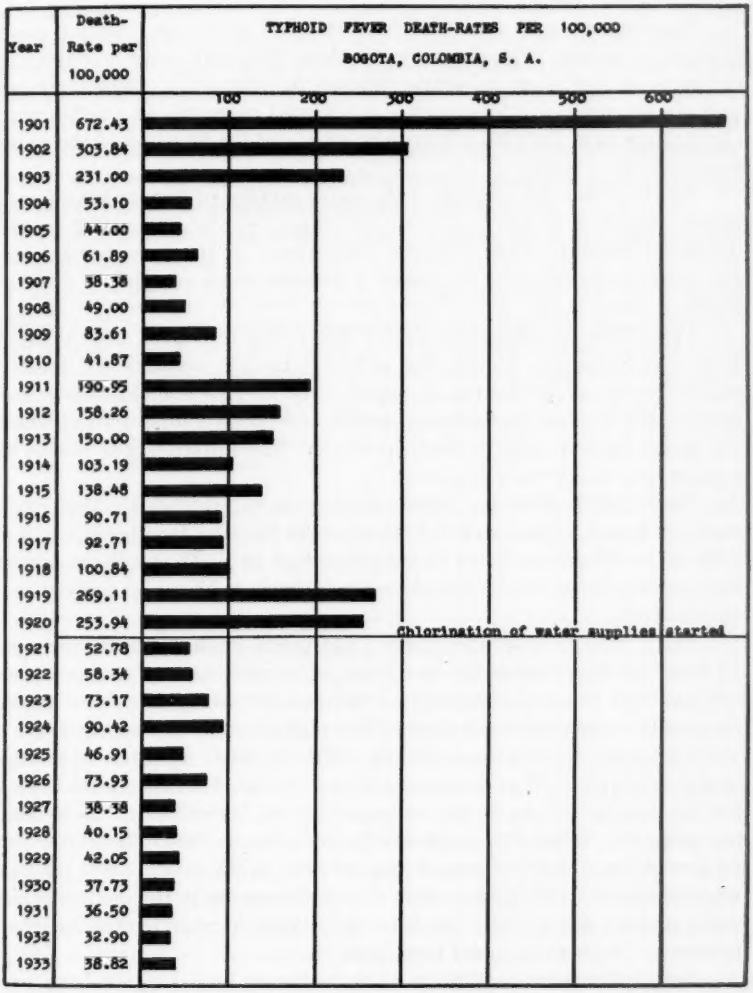

FIG. 9.— ANNUAL DEATH RATE FROM TYPHOID FEVER PER 100,000 POPULATION, BOGOTA, COLOMBIA, S. A.

delays in shipments from the United States. Operation of the chlorinators was placed in charge of a local bacteriologist who was assisted by one field inspector. Selection of a new water supply which, together with the largest of the old supplies, would be developed to replace the five scattered supplies was not made until December, 1933, when the author was recalled by the government to decide on one of the two supplies under consideration. If no further delays occur, an adequate supply of filtered water should be available in the first part of 1937.

Approximately 16 years will have elapsed before the filtration plant is placed in service. This illustrates the delay that may occur in improving the water supply of an important Spanish American city. Such instances indicate the need of chlorinators as a remedial measure. In another city, chlorinators were installed a few years later, and the filtration of the water supply is yet to come.

To show that chlorination of the water supplies of Bogota has effected results, Figure 9 is reproduced from a report published in 1932 by the Technical Director of the National Department of Hygiene of Colombia, Dr. Enrique Enciso, who has made a detailed study of typhoid fever in Bogota.

From 1886 to 1889, there were 1 823 deaths in Bogota from typhoid fever and dysentery. During this period, a private company constructed the first water works, taking the supply from the San Francisco River and distributing it to public buildings, parks, and public hydrants from which the people carried water to their dwellings. The installation of sewers to replace open canals was also started.

From 1889 to 1898, the distribution system was extended so that water was distributed to nearly all the residences in the city, but the supply was polluted by the people living on the catchment area. The southern part of the city was served with polluted water taken from the old colonial Belen Water Works.

From 1900 to 1903, there were 1 411 deaths from typhoid fever and 1 148 deaths from dysentery, as a result of accumulation of troops during the last civil war and unsanitary conditions prevailing in prisons where thousands of persons were lodged. The graph starts with the year 1901.

During the five years following, 1904 to 1908, inclusive, epidemics ceased, but typhoid fever remained in endemic form. The explanation offered for the drop in the death rate of typhoid fever, as well as in the general mortality rate, is that the people who survived the war had either developed an immunity or that the general improvement in the sanitation of the city was responsible. It is quite certain that improvement in the quality of the water supplies was not responsible for the sudden decrease in typhoid fever, because no improvement had been made.

During the term of 1909 to 1918, inclusive, both typhoid fever and dysentery reappeared with the characteristics of epidemics. Due to lack of water from the supplies in service, another supply was developed in 1911

from the San Cristobal River which was polluted by a nearby road that was converted into a public latrine by the adjacent population. In 1914, the municipality took over the water works and started to purchase and clean up the catchment areas of the water supplies.

During 1919 and 1920, epidemics of both typhoid fever and dysentery developed to such proportions that the hospitals could not accommodate the cases, and it became necessary to establish others. The mortality from typhoid fever increased to approximate the rates of 1902 and 1903. During the construction of a munitions factory on the banks of the San Cristobal River, above the intake of the water works, the laborers used the bed of the river as a latrine, and the water, thus polluted, was distributed through a large portion of the city so that nearly all of the population were victims of the infection. The dysentery cases consisted of the bacillary and amebic types. This was an excellent example of mass infection of a water supply and of the transmission of amebic dysentery by water.

In reference to the chlorination of the water supplies, Dr. Enciso made the following observation:

> The chlorination of the principal water supplies of the city was started on December 21, 1921, a measure that ended the epidemic form of typhoid fever and dysentery, with its effect emphasized when it was observed on suspending this sanitary measure that outbreaks occurred which, even if they should be classed as epidemics according to modern standards of hygiene, never could be compared to those which had occurred during the past. While the annual coefficients of mortality are still very high many of the deaths occur among inhabitants of neighboring communities who have contracted the disease outside of the city.

The increase in the death rates of typhoid fever to 73.17, 90.42 and 73.93 in the years of 1923, 1924, and 1926, respectively, was due to suspensions in chlorination during short periods, not exceeding 30 days. The outbreaks of typhoid fever which invariably followed the suspensions offer excellent evidence that disinfection of the water supplies was of value in reducing the deaths from the disease. While improvements and additions have been made to the distribution system of the water works, pollution of the water supplies has not been stopped so that chlorination is the only line of defense now in service against the recurrence of epidemics of typhoid fever and dysentery. Undoubtedly the death rate of 32.9 per 100 000 in 1932 would be reduced if the water supplies were not subject to intermittent addition of large amounts of organic matter and turbidity during rains on the watersheds which reduce the effectiveness of chlorine. Starting in January, 1933, the operators at the intakes of the water supplies were instructed to discontinue the flow of water into the distribution system during periods of high turbidity in the streams. This practice reduced the number of pathogenic bacteria which escaped chlorination.

Another example of the efficiency of chlorination in reducing typhoid fever is furnished by Quito, the capital of Ecuador, with an estimated population of 100 000. Chlorination of the water supply was started on

October 1, 1928, and effected a marked reduction in the number of cases of typhoid fever, as Table 6 shows.

TABLE 6.— CASES OF TYPHOID FEVER IN QUITO, ECUADOR.

Year.	No. of Cases of Typhoid Fever.
1924	287
1925	241
1926	321
1927	494
1928	373
1929	133
1930	55

According to Dr. Pablo Enrique Albernez S., Director of Municipal Hygiene, there was very little modification in the other factors relating to the transmission of this disease.

The first installation of chlorinators in Colombia, made by the author at Barranquilla in June, 1920, produced odd and interesting results. At that time, the water works were operated by a private company and consisted of an intake in the Magdalena River, pumps operated by steam generated in wood-burning boilers, a distribution system of cast-iron pipe, and a small storage reservoir. As it appeared that there would be a considerable delay before construction of a filtration plant would be started, installation of chlorinators was recommended as the first step toward the purification of the water supply. The author takes this opportunity to state that credit for starting the movement in Colombia to reduce the mortality from water-borne diseases by the chlorination and filtration of public water supplies belongs to the late General Pedro Escolar, manager of the private water works company in 1920.

A few months after the application of chlorine began, a local physician started a campaign against its use and in favor of ozone. All sorts of exaggerated statements were made about the effect of chlorine on the human system, such as increasing the death rate from tuberculosis and and cancer, but the most startling and morale-shattering claim was to the effect that the drinking of chlorinated water would render the male population impotent. This argument served as the last straw to break the back of the water company, and it was forced to discontinue chlorination of the water supply, although a special order had been issued by the Director of the National Department of Health to continue it. This marked the end of the first attempt to introduce chlorination into Colombia.

Now and then the author is told about this experience, the *raconteur* not knowing that the listener was responsible for all the excitement. It has been surprising to learn the wide circulation of articles against chlorination written by the local physician who started the campaign against it. While talking with the representative of an ozone company in New York early

in 1935, the author was greatly surprised to be shown a tabulation of the claims made by this same physician against chlorination and in favor of ozonization under the belief, apparently, that it was the work of an authority.

Later the municipality of Barranquilla took over the water company, and in 1929 a modern rapid sand-filtration plant was placed in operation. The same physician made an attempt to prevent the application of chlorine to the filtered water but failed in his efforts, although he carried on a vigorous newspaper campaign.

Filtration. In some respects slow sand-filtration is preferable to rapid sand-filtration in Spanish American countries. Operation of a slow sand-plant is less complicated, and operating expenses are less than those of a rapid sand-plant, due to elimination of a coagulant, if the fixed charges are overlooked as is generally the case in accounting systems of water works in the tropics. The majority of the small rivers are of a flashy character and carry high turbidities and considerable color after rains with the result that a coagulant and settling basins are required to prepare the water for the filters irrespective of the type used. The author believes that a rapid sand-filtration plant is more practical in the majority of cases.

The first studies and reports on the sanitation of Spanish American cities were made by English firms who recommended slow sand-filtration plants. As a result, it has been necessary for the author to discuss the relative merits of slow and rapid sand-filtration in several cases and to demonstrate that the latter method was preferable for water supplies derived from rivers of low turbidity during a few months and of widely fluctuating turbidity during the remaining months of the year.

To the author's knowledge there are only two slow sand-filtration plants in operation within the tropics at the present time. The J. G. White Co. of London, England, constructed a 5.25-m.g.d. plant as a part of the new water supply system of Guayaquil, Ecuador. The raw water is taken from a river. San Jose, Costa Rica, has two slow sand-filters, each 0.37 acre in area, for purifying river water to supplement the ground water supply.

The experience of the author leads him to the conclusion that the personnel required for the operation of a rapid sand-filtration plant may be developed from the Spanish Americans without any great difficulty if they are given careful and patient training. The greatest danger that exists, and one that is not unknown in the United States, is that trained personnel may be changed when either the administration of the water works or the political party in power is changed. The importance of maintaining trained personnel in a filtration plant, entirely independent of political changes, must be called to the attention of the various officials in a very emphatic manner and great stress laid upon it when a plant is placed in service. The author always calls the attention of the municipal council, the various officials, and the public to the fact that in obtaining a modern

rapid sand-filtration plant the city also acquires a great responsibility for its proper operation and maintenance and that it must not be considered as a new mechanical toy that requires only the winding of a spring to make it run.

In selecting a site for a filtration plant, an effort should be made to obtain one reasonably close to the city so that it will be accessible at all times for the transportation of supplies and for supervision. It is preferable to select a site on an elevation which commands a view of the city, or a part of it, and of the surrounding country, providing the topography permits and any extra expense involved is not excessive. Such a site can not be obtained always, but at least the plant should not be tucked away in a depression merely to satisfy the hydraulic computations of some engineer

FIG. 10.— RAPID SAND-FILTRATION PLANT AT CALI, COLOMBIA, S. A.; CITY IN BACKGROUND; NOMINAL CAPACITY, 8 M.G.D.

who is lacking in imagination. It should be borne in mind always that a filtration plant is being built not only to purify and distribute water but also to serve as a monument to the progress of a city and as an addition to existing parks.

The buildings of a filtration plant should be designed so that they will present an interesting and attractive picture to which the people may point with pride. Enough ornamentation should be provided to add the finishing touches, but it should not be overdone. Contrary to the opinion held by many North Americans, the Spanish Americans do not demand that a building be covered with ginger-bread-work to render it pleasing and attractive. The architectural treatment will be influenced greatly by the climate. "Modernized" styles of architecture are supplanting the Spanish style in several South American cities.

The grounds surrounding a filtration plant are gradually adorned with flowers, shrubs, palms, etc. as money becomes available, with the result

that they are converted into a park on a small scale. Within a short time after a new and modern filtration plant is placed in service, the majority of the population develops a great pride in it. It serves as an exhibit to be visited on Sundays and holidays by the local population, by people from other sections of the country and by foreigners passing through the city. While it is something which can not be measured, the influence of a filtration plant as a stimulant in improving the water supplies of other cities is a real force.

Future extensions to a filtration plant should also be kept in mind in selecting a site, if the initial capacity is less than the volume of water which may be obtained from the supply under development, or if water from another source may be conveyed to the plant in the future. In preparing the plans for a filtration plant, it is important to provide for future extensions to the various units and to indicate the latter on the general plan so that the necessary areas may be reserved. Provisions should be made for connecting the extensions to the first units. In some cases pipes, solution tanks, mixing tanks, etc., should be installed to take care of the ultimate capacity of the plant, but this depends on whether or not more than one extension will be made.

A program for future extensions is an essential feature of the development of a municipal water supply to avoid endless discussions and delays when more water is required. Water supply engineering is in an embryonic state in the tropics, and considerable time will elapse before the graduates from sanitary engineering courses are qualified to handle the problems in this field, even though they have received excellent education in the fundamental theories. Many of the graduates are forced to take jobs on highway or railroad construction in order to earn a living on account of the lack of work in their line, with the result that they do not obtain the necessary experience to handle a water works job when it develops.

Between sea level and an elevation of about 4 100 ft., rapid sand-filters, mixing chambers and settling basins may be left uncovered. With only a covered operating floor, open on the sides, a considerable reduction may be effected in the cost of the filter building, and a very pleasing architectural effect may be obtained.

If a filtration plant is located at an elevation of 8 000 to 10 000 ft., where the temperature falls to about 40°F., with rains of considerable frequency, or heavy mists, and there are chilly winds, it is preferable to enclose the filters to make conditions more comfortable.

The only serious objection to uncovered filters which requires consideration is the growth of algæ on the walls, but the rate of the growth may be greatly reduced by painting the walls from the top of the filter to the sand with black asphalt paint. The paint not only darkens the walls but makes them smoother and their cleaning easier. A monthly cleaning of the black walls by a deck broom, with flushings by a hose at every filter wash, will prevent the formation of any objectionable amount of algæ.

If the plant is located in a region of heavy rainfall with frequent winds of rather high velocity, the sides of the operating gallery should be enclosed either with glass windows or doors, with the latter hung on an overhead rail so that they may be pushed back between storms or when the filters are washed. Likewise it is preferable to cover the mixing chambers, if mechnical agitators are used, and the well or section of the conduit to which the chemicals are applied so that the operators may attend to chemical treat-

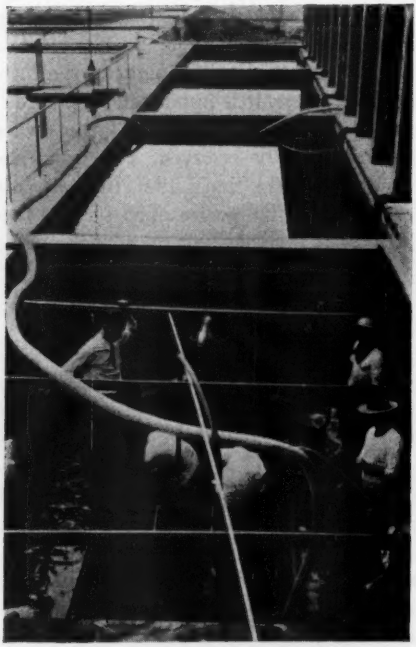

Fig. 11.— UNCOVERED FILTERS AT CALI, COLOMBIA.

Covered operating floor on right and open settling basins at left. Washing 3–4 inches of top sand in filter after treatment with caustic soda.

ment of the raw water, without working in a rainstorm, especially when there are frequent changes in the turbidity.

If flocculators are installed in the settling basins with preliminary rapid mixers, it is advisable to place the latter under cover and to provide for taking samples of the treated raw water flowing to the flocculators after passing through the mixers so that the operators may control the chemical treatment of the water without working in a rainstorm.

If the capacity of the plant and other conditions are such that rather large mixing chambers of "around-the-end" type are used, instead of

mechanical agitators, it is hardly practical to cover them. In such cases, if a raw water of rapidly changing characteristics is being treated and the operaters must inspect the mixing chambers at frequent intervals during a rainstorm, a short coat and pants of rubber provide good protection. In some cases a covered walk may be provided between the chemical treatment room and the mixing chamber.

On first consideration, it may appear that the mixing of the coagulant with a raw water by mechanical agitators is the solution of the problem in regions of heavy or frequent rains, but a disturbing factor is the interruption which often occurs in the electric power, especially where it is generated by hydro-electric plants to which water is brought in open canals running along hillsides. Interruptions may be due to slides or to damage to the transmission lines by high winds. If the power company does not have a Diesel engine standby plant to cut into service when the hydro-electric plant is shut down, the power to the water works may be off several hours. With a wind of high velocity during a heavy rain, no power for operating dry-feed machines, mechanical agitators, and pumps for the wash water tank, and with a raw water of high turbidity entering a filtration plant, operation becomes rather hectic if the volume of filtered water in the reservoir is not large enough to permit a shutdown.

In designing plants, the possibilities of interruptions in electric power must always be considered in relation to the following equipment: choice of dry-feed machines or solution tanks; of mechanical agitators or baffled mixing chambers; a standby pump driven by a gasoline motor for keeping water in the wash-water tank; a standby unit for pumping into the distribution system; or a Diesel engine standby unit for generating power for all purposes. Occasionally conditions are such that power may be generated in a plant by taking advantage of the head available in the raw-water supply line.

Where conditions permit, except in the case of cities with standby power equipment, it is preferable to install a gravity system throughout so that pumping is eliminated except to the wash-water tank, and to eliminate dry-feed machines and other motor-driven equipment. To take care of the illumination at night, if the power goes off, lanterns should be provided which will withstand high winds.

It is the opinion of the author that a filtration plant with a head house at one end of a long settling basin and a filter building at the other end is not practical in a region subject to heavy and frequent rains unless the topography of the site selected necessitates such a design. If such is the case, serious consideration should be given to the selection of another site with more favorable topography. If the characteristics of the raw water change infrequently, there are no serious objections to a plant of such design if the topography of the best site demands it.

Settling basins in plants handling warm waters require cleaning with greater frequency than those in cold-water plants, not because of depth of

sludge but because of fermentation and putrefaction which are active enough at periods from seven days to a month to produce sufficient gas to raise pieces of the sludge to the water surface and add odor and taste to the water traveling through the basins. Unless fermentation of sludge is prevented, settling basins should be emptied and washed at intervals not to exceed 30 days when the temperature of the raw water averages 77 to 80°F. or higher, and once in two months when the temperature of the raw water averages 64 to 70°F.

The author is an advocate of the air-washing of filters, prior to water washing, in plants located in a region of high temperature and dealing with

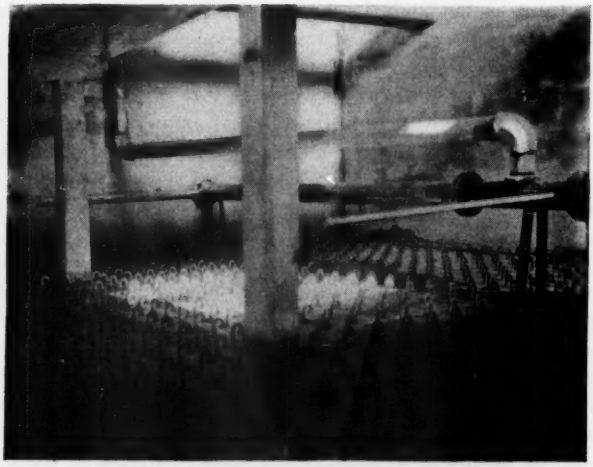

FIG. 12.— ⅜-IN. FEED PIPES IN FALSE BOTTOM OF MIRAFLORES FILTERS.

The strainers were removed when the filters were overhauled in 1922. At right center is an air manifold with two laterals in position. Area of filter is 21.5 by 19.75 ft. Nominal capacity, 1.22 m.g.d.

warm surface waters. In addition to assisting in keeping the sand in good condition, air wash removes odors which have accumulated in the sand bed and thus maintains it in a sweeter condition. In the operation of the filtration plants in the Canal Zone, the wash water is applied at the rate of 15 gal. per sq. ft. per min., following an air wash of about 4 minutes, instead of the lower rate of 7 to 10 gal. as used in other plants. Washing by air and water applied together has been tried, but the results have been unsatisfactory. The installation of a separate air-piping system in the fine gravel below the sand is preferred to delivering air through the wash-water distribution system on the bottom of a filter.

The first rapid sand-filters with reinforced concrete false bottoms were designed by Geo. M. Wells[31] for the Miraflores filtration plant[32] in the Canal Zone. They were placed in service in March, 1915, and have required

a complete overhauling only once during the past 20.5 years of operation. The overhauling was made necessary by the clogging of most of the strainers by sand in 1922. With the removal of the strainers from the ⅜-in. brass feed pipes, spaced 6-in. center to center, the one source of trouble was eliminated; 24 in. of graded gravel were placed over the false bottom when the filters were constructed and were replaced during the overhauling.

A serious objection to the Harrisburg type of filter bottom is the difficulty, if not impossibility, in assembling a manifold and cast-iron laterals, with threaded ends, so that the free ends of some of the laterals do not rise above or fall below the ends of the others. A lot of time is lost in changing laterals in an endeavor to set the battery on either side of a manifold in the same horizontal plane, and in the end a few laterals generally stick up above the others. Even though the first cost of the Miraflores type of filter bottom may be higher than that of the Harrisburg type, the maintenance cost of the former type is lower, and operating troubles are less.

In designing a filtration plant, especially in the interior of a country, more storage space must be provided for alum, chlorine, and other imported chemicals than would be allowed in a plant in the United States, to take care of ordinary delays in transportation from the seaport to the city in which the plant is located. In addition to what may be termed operating space, additional storage space should be provided for reserve storage so that a sufficient stock of chemicals will be on hand to take care of unusually long delays in transportation.

In the case of chlorine, enough extra cylinders must be carried for the treatment of water during a period varying from one week to one month, in addition to those required for the operating periods between regular shipments, depending upon the distance from the port of entry. This involves the purchase of a larger number of cylinders than would be required in the United States. The use of one ton containers is out of question because of the number of times freight must be handled.

The cost of chemical treatment of water supplies is much higher than at most filtration plants in the United States, unless the plant is located in a city which serves as a port of entry to the country. Inland transportation of the chemicals adds greatly to their cost at the point of manufacture. When the exchange rate is unfavorable to the purchaser, the cost of an imported chemical is again increased. In addition to transportation costs, duty must often be paid, even though a municipality is operating the water works. There are no chemical plants for manufacturing aluminum sulphate or any other coagulant. Up to the present time, there is no production of bauxite, although deposits undoubtedly exist, and even if there were, sulphuric acid would have to be imported for manufacturing a syrup of aluminum sulphate at a filtration plant.

Up to the present time, aluminum sulphate has proved to be the lowest-priced coagulant. The cost placed in a plant may vary from a minimum of

150 per cent. to a maximum of 500 per cent. greater than at the point of manufacture in the United States. Money may be saved by purchasing it in bags instead of in barrels, and in most places the bags may be sold for as much as 28 cents for one double bag. The bags are used for the transportation of corn, coal, vegetables, etc. The greater part of the aluminum sulphate used is purchased in the United States. Alum stored in bags takes up a small per cent. of water in a region of high humidity, like the Canal Zone, but not enough to be of practical importance.

Providing there is sufficient filtered water storage, alum may be saved by shutting down the filtration plant during three to four hours and by-passing the highly turbid raw water in small rivers following heavy rains on the catchment area. In many cases the heavy rains are of short duration, with the result that the turbidity of the raw water, caused by the erosion of beds or banks of clay, rises quickly to a maximum of 2 000 to 4 000 p.p.m. and drops back to 100 to 200 p.p.m. within 2 to 3 hours.

The cost of liquid chlorine in cylinders, placed in a filtration plant, varies in about the same proportions as those given for alum, the cost of returning the empty cylinders being included. Importation of caustic soda or soda ash makes the cleaning of filter sand rather expensive.

In many cases, there are deposits of limestone from which quicklime is made in small kilns. The lime must be taken as it comes out of a kiln in pieces of various sizes and converted into milk of lime for application to the water. To use the quicklime as produced in a continuous dry feeder and slaker, it would be necessary to install a crusher to break up the pieces of irregular size from the kiln. This is not practical in small plants. For the transportation of the quicklime from the kiln to the plant, by truck or train, metal drums or barrels with covers must be provided by the water works to prevent airslaking, as the kiln may be located at some distance from the plant. Hydrated lime is not obtainable. The importation of hydrated lime or granulated quicklime for use in dry-feed machines is not practical, both from the standpoint of cost and objections to the importation of a material which is produced in the country.

The author does not know of any water softening plants operated either by municipalities or private companies in the tropics, and he believes that considerable time will elapse before softening will be undertaken. The high cost of salt in many places is a handicap for the zeolite process.

Ordinary bleaching powder loses its strength rapidly under climatic conditions prevailing in the Canal Zone. High-test hypochlorite loses strength very slowly, and the author recommends it for use in the tropics, especially for treating water supplies used by an army, during a war, at isolated army posts, or in small communities located off the main lines of transportation. For such conditions, a simple apparatus for applying a solution of high-test hypochlorite is more practical than a chlorinator, as it may be kept in condition without importing any parts and is better adapted to the type of men who manage its operation. A network of roads is not yet available for

a mobile purification unit comprising a filter and chlorinator on a truck.

Simplicity of operation and maintenance should always be kept in mind in designing filtration plants for the tropics. The greater the reduction that can be made in the number of items of plant equipment requiring frequent attention to maintain them in good working condition, the better will be the results obtained. For this reason, the author does not favor operating tables with four-way cocks and valves operated by hydraulic cylinders, or electric motors, in plants with filters of 1.0-m.g.d. capacity or less. It has been his experience that hand-operated valves require less attention and reduce the cost of maintenance. If an air wash is provided for the filters, air valves with renewable discs should be used in preference to metal to metal seats which require grinding when they leak. Controllers of the direct-acting type are preferable to the indirect type with pilot valves and hydraulic cylinders.

Aëration Aëration is a very essential feature of water purification in tropical countries, not only for reducing the intensity of odors produced by algæ but also for removing odors of fermentation and putrefaction. It should be taken as an axiom that water supplies drawn from rivers and impounded reservoirs in regions of low altitude in the Torrid Zone should be aërated prior to delivery to consumers. Whether the raw or filtered water, or both, should be aërated will be determined by local conditions. Whether aëration is required for water supplies at higher altitudes depends upon several factors that should be investigated carefully before filtration plants are designed.

The raw-water aëration basin of the Mt. Hope filtration plant, Canal Zone, 60 by 66 ft. in plan, was equipped with 85 cone nozzles which were arranged in 5 batteries of 17 each. The nozzles were so adjusted that, under ordinary operating conditions, the raw water was discharged at an angle of 30 deg. in a thin sheet which broke up into fine drops. The average diameter of the circle formed by the discharge of one nozzle striking the floor was 24 ft. The average loss of head due to the nozzle itself was 1.95 ft. With the nozzles adjusted for maximum flow, water was discharged in the form of a sheet of varying thickness without any spraying. Under these conditions the average diameter of the circle formed by the discharge of one nozzle striking the floor was 10 ft. The average loss of head due to the nozzle itself was 0.5 ft. Table 7 furnishes typical illustrations of the action of the nozzles as operated in 1916.

With increased amounts of free carbon dioxide in the raw water, better reduction was effected by spraying action of the nozzles. The removal of disagreeable odors was also more efficient. An odor of hydrogen sulphide of a numerical value of 5 (Whipple's scale) was completely removed by the spraying action of the nozzles.

Table 8 shows the reduction in free carbon dioxide effected by aëration of the raw water at the Mt. Hope plant during a period of 12 months ended June 30, 1916.

TABLE 7.— EFFECT OF NOZZLES IN THE AËRATION BASIN OF THE MT. HOPE FILTRATION PLANT. CANAL ZONE.

Source of Sample.	Temperature. °C.	Dissolved Oxygen.		Free Carbon Dioxide; p.p.m.
		p.p.m.	Per cent. Saturation.	
Ordinary Operating Conditions.				
Raw water tap	28.8	5.09	65.2	2.5
Discharge from: Aëration basin	28.0	7.38	93.1	0.0
Maximum Flow of Water.				
Raw water tap	29.5	4.37	56.7	3.5
Discharge from: Aëration basin	29.2	6.76	87.2	1.5

TABLE 8.— REDUCTION IN FREE CARBON DIOXIDE BY AËRATION OF RAW WATER AT THE MT. HOPE FILTRATION PLANT, CANAL ZONE.

Month.	Raw Water, p.p.m.				Aërated Water, p.p.m.			
	Median.	Mean.	Max.	Min.	Median.	Mean.	Max.	Min.
1915								
July	3.0	3.0	5.0	1.0	1.0	1.0	5.0	0.0
August	1.0	0.7	1.0	0.0	0.5	0.3	0.5	0.0
September	0.5	0.8	3.0	0.0	0.0	0.2	0.5	0.0
October	3.0	2.7	4.0	0.0	1.0	0.8	2.0	0.0
November	2.0	2.3	4.0	1.0	0.5	0.7	1.0	0.5
December	2.0	2.3	6.0	0.0	0.5	0.6	1.0	0.0
1916								
January	1.0	1.3	5.0	0.5	0.5	0.4	1.5	0.0
February	1.0	0.8	1.0	0.0	0.0	0.0	0.0	0.0
March	2.5	2.6	4.5	0.5	0.5	0.5	1.0	0.0
April	2.5	2.6	4.5	1.0	0.0	0.1	0.5	0.0
May	1.5	1.7	4.5	0.0	0.0	0.1	0.5	0.0
June*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

*Carbonate alkalinity.

The raw water for the Mt. Hope plant was taken from an impounding reservoir, known as Brazos Brook. The dissolved oxygen in the raw water, during the year ended June 30, 1916, varied from 1.75 p.p.m. (22.2 per cent. saturation) when the bottom intake, 25-ft. below the surface, was in use, to 9.0 p.p.m. (119 per cent. saturation) when the surface intakes were in use. In the former case, the effect of aëration was to increase the dissolved oxygen to 7.15 p.p.m. (90 per cent. saturation); in the latter, there was a reduction to 7.76 p.p.m. (101 per cent. saturation). On August 9, and November 20, 1915, the nozzles reduced the dissolved oxygen from 8.04 and

8.38 p.p.m. (105 and 107 per cent saturation) to 7.96 and 7.93 p.p.m. (102 and 100 per cent. saturation).

The raw-water aëration basin of the Miraflores filtration plant, Canal Zone, 86 by 125 ft. in plan, was equipped with 105 nozzles, which were arranged in 7 batteries of 15 each. The nozzles were so adjusted that, under ordinary operating conditions, the raw water was discharged at an angle of 20 deg. from the vertical in a thin sheet which broke up into coarse or fine drops, depending upon the height to which the water was thrown. This height averaged about 10 ft.

Table 9 shows the reduction in free carbon dioxide effected by aëration of the raw water at the Miraflores plant during a period of 12 months ended June 30, 1916.

Table 10, prepared from 37 determinations, shows the increase in dissolved oxygen effected by aëration of the raw water.

TABLE 9.— REDUCTION IN FREE CARBON DIOXIDE BY AËRATION OF RAW WATER AT THE MIRAFLORES FILTRATION PLANT, CANAL ZONE.

Month.	Raw Water, p.p.m.				Aërated Water, p.p.m.			
	Median.	Mean.	Max.	Min.	Median.	Mean.	Max.	Min.
1915								
July	3.8	3.6	5.5	1.2	1.5	1.6	3.8	1.0
August	4.0	4.2	6.5	3.0	1.5	1.65	3.0	1.0
September	4.0	4.1	7.0	1.5	1.5	1.63	3.0	0.5
October	4.5	4.9	8.0	3.5	2.5	2.4	3.5	1.5
November	4.0	3.8	7.0	1.5	1.5	1.65	3.5	0.5
December	3.0	2.9	4.5	1.5	1.5	1.37	2.0	1.0
1916								
January	3.5	3.5	5.0	2.0	1.7	1.7	3.0	1.0
February	3.5	3.55	4.5	2.5	1.5	1.65	2.5	0.5
March	4.0	4.1	5.0	3.0	2.0	2.2	4.0	1.0
April	5.0	4.9	6.0	3.0	2.5	2.3	3.5	1.5
May	4.5	4.7	7.0	3.5	2.0	2.0	2.5	1.0
June	4.0	3.9	6.0	2.5	1.5	1.6	2.5	0.5

TABLE 10.— EFFECT OF AËRATION ON DISSOLVED OXYGEN CONTENT OF RAW WATER, MIRAFLORES FILTRATION PLANT, CANAL ZONE.

Thirty-seven Determinations.	Dissolved Oxygen.			
	Parts per Million.		Per cent. of Saturation.	
	Raw Water.	Aërated Water.	Raw Water.	Aërated Water.
Median	4.43	7.50	62.5	92.0
Mean	5.23	7.64	64.4	94.3
Maximum	7.30	8.03	77.0	78.0
Minimum	3.20	6.66	40.7	84.0

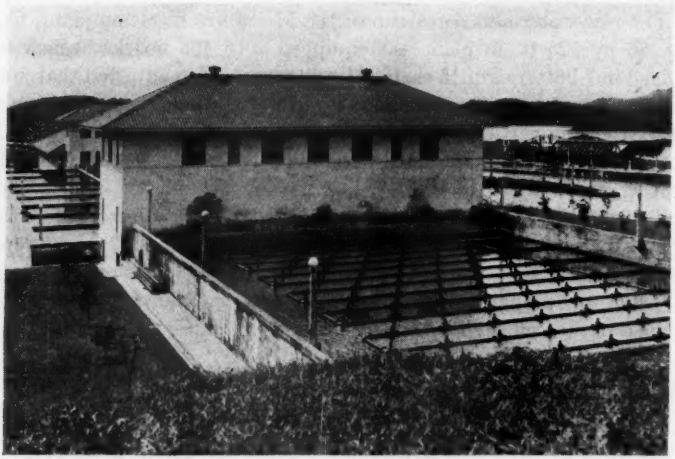

FIG. 13.— RAW-WATER AERATION BASIN, MIRAFLORES FILTRATION PLANT, PANAMA CANAL ZONE.

Head house at left center; settling basins and filter building at extreme left center; Miraflores locks at right center.

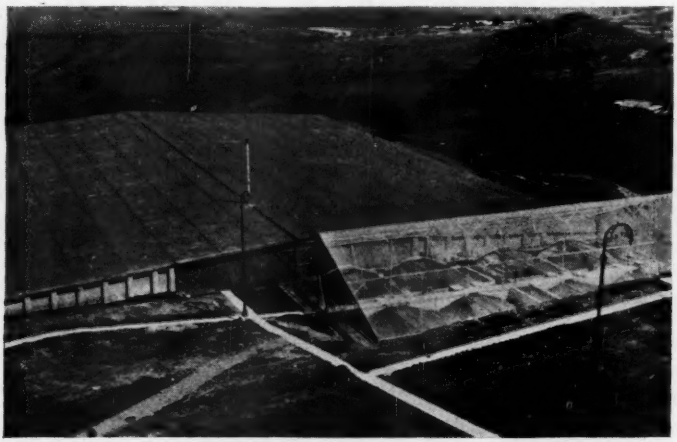

FIG. 14.— CALI FILTRATION PLANT, CALI, COLOMBIA, S. A.

Aërator covers with galvanized wire mesh and adjacent combined clear-water well and distributing reservoir of galvanized copper-bearing steel sheets.

The varying intensities of the odors in the raw water were always reduced by aëration to an intensity not greater than 1, using Whipple's scale as a basis, except in a very few instances.

In the Mt. Hope aëration basin, the nozzles were spaced 6 ft. apart, center to center, on each of five parallel lines which are also spaced the same distance apart. In the Miraflores aëration basin, the corresponding spacing was 8 ft. In each basin, the nozzles were staggered to obtain a triangular grouping.

The author recommends the covering of filtered-water aërators with wire mesh to prevent bugs, birds, and leaves entering the water, and children or visitors throwing various objects into it. Figure 14 shows how an aërator of the "cascade" type, at the Cali, Colombia, filtration plant,[33] was covered with $\frac{3}{16}$-in. galvanized wire mesh. Here, during certain months, there are swarms of bugs, resembling "June" bugs in the United States, many of which would drop into an uncovered aërator, pass through the reservoir, and enter the distribution system. Before the plant was built, these bugs fell into the open distributing reservoir, sank, and passed into the distribution system to plug the small service pipes or to appear in the water drawn from faucets.

The local manager of the water works wished to enclose the aërator in a building, but the author prevailed upon him to construct a cover of wire mesh so that the water would be exposed to sunlight and air. The covering has proved to be a success, and the numbers of bacteria in the water entering and leaving the aërator, as determined at 37.5°C., have been practically equal during the 5 years of operation. Chlorine is added to the combined filter effluents as they flow to the aërator. At the end of five years, the wire mesh was in good condition, with the exception of a few places where the strips had pulled apart a little along the joints which were laced together with wire. These openings were covered with patches.

As a result of difficulties encountered in cleaning aëration basins, the author makes the following recommendations: the floor should be sloped to a central gutter so that algal growths removed from the concrete and the pipes may be flushed into the drain with hose streams without using scrapers; the drain should be made large enough so that the dirty water will not back up and slow down the cleaning; the necessary pipe lines with hose outlets should be provided for flushing the basin with water under high pressure. In cleaning a filtered water aëration basin, provisions must be made for preventing dirty water from entering the conduit through which the aërated water flows to the filtered-water reservoir.

Covering of Filtered Water Reservoirs.

The author has discussed the covering of reservoirs for filtered and ground waters in a paper published in a past issue of the Journal[34] of this Association, and his later experience has confirmed the conclusion stated in that paper, namely, that an open service reservoir for storing filtered or

ground water has no place in a well-designed system of water works either in tropical or temperate zones.

At Cali, Colombia, there is a 2-m.g. distribution reservoir, lined with concrete, and covered with a galvanized-steel roof laid over a steel framework; it measures 190 by 150 ft. in plan at the top and 150 by 110 ft. at the bottom and is 14 ft. deep. The walk on the division wall is 8 ft. 4 in. below the ridge of the roof, and at maximum elevation the water surface is about 1 ft. lower. On the long sides of the reservoir, the vertical distance from the roof to the maximum water level is about 2 ft. 6 in. The effluent from the covered aërator, previously mentioned, flows into this reservoir which also serves as a clear-water well.

In July, 1932, the writer made a test to determine the effect of the hot air between the roof and the water on the temperature of the outflow from the bottom of the reservoir to the distribution system. The detention period in the reservoir ranged from 3 to 6 hours.

The temperature of the air inside the reservoir, 18 in. below the ridge of the roof, rose from 71°F. at 7:30 A.M. to 113°F. at 3:00 P.M.; dropped to 86°F. at 5:45 P.M.; and then gradually fell during the night to 68°F. at 5:00 A.M. The maximum air temperature outside the reservoir, as determined on a sheltered thermometer, was 88.5°F. and the minimum was 62°F. On sunny days, water of condensation started to drip from the under side of the roof at about 8:00 A.M.

The temperature of the air inside the reservoir, taken at the level of the walk on the division wall, reached a maximum of about 93°F. between noon and 2:00 P.M., 20°F. less than the maximum under the ridge; then dropped gradually to about 75°F. at 6:00 P.M.; and reached a minimum at 6:00 A.M. of 67°F.

The temperature of the surface water in the reservoir was 68°F. at 6:00 A.M.; 67 to 68°F. between noon and 2:00 P.M.; and reached a maximum of 70°F. at midnight. The temperature of the water entering the reservoir from the aërator ranged from a minimum of 65°F. during the forenoon to a maximum of 71°F. late in the afternoon so that the warm air in the reservoir raised the temperature of the surface water by 2 to 3°F. above that of the aërated water. Other tests showed that the temperature of the water was not increased during its flow through the aërator.

As the consumption in the city started to increase at about 4:30 A.M., the level of the water gradually dropped from about a ft. below the walk on the division wall to about 7 ft. near 10:00 A.M. and remained at this level until 10:00 P.M. when it started to rise and returned to the maximum elevation at about 3:00 A.M. Undoubtedly the difference in temperature between the inflow and the surface water in the reservoir would have been greater if the latter had been maintained at the maximum elevation throughout the test so as to provide a longer detention period.

On another day, temperatures of the water entering the aërator and of the water flowing through the 24-in. outlet of the reservoir were taken each

hour during a period of 24 hours. The temperature of the outflow was 0.4 to 1.8°F. higher than that of the inflow to the reservoir during about 14 hours and practically the same during the remaining 10 hours.

Small screened openings were provided on each of the long sides of the reservoir for ventilation, and also some openings at each end, but better circulation of air and lower temperatures would be obtained by ventilators set along the ridge of the roof. With thorough ventilation of a reservoir with a galvanized steel roof, it is probable that the temperature of the water passing through it would not rise more than 1°F. providing the maximum detention period is not more than 12 hours.

A test was also made in the same reservoir to determine the evaporation. A weighed amount of water was placed in a pan which floated on the surface of the water during the fluctuations in the elevation. The test was run under the temperature conditions given in the preceding paragraphs. The loss of water by evaporation amounted to 369 gal. per 24 hours from a water surface of about 3 156 sq. yd.

Immediately after the roof had been laid, it was treated with a solution of copper sulphate and a green paint applied. At the end of 5 years the paint had peeled off from so many small and scattered areas, and looked so bad, that it was necessary to repaint the roof. The old paint was removed by covering a section of the roof with sawdust; soaking it with a solution of soda ash (1:10 by weight) for 1.5 hours; and then scrubbing it with brushes. Two coats of dark red "Cemtex" (No. 1007) paint were applied in May, 1935. The cost of cleaning and painting the roof is shown in detail below:

	Cost in Pesos.
105 gal. of "Cemtex"	462.42
Labor	154.00
705 lb. of soda ash	35.25
12 paint brushes	12.50
45 gal. turpentine	67.50
12 brushes	18.00
Miscellaneous	30.00
Total	779.67
Cost per sq. yard	21.7 centavos

There are seven reinforced concrete distributing reservoirs in the Panama Canal Zone water supply systems, the largest holding 2 m.g., which are covered with roofs of concrete without superimposed earth. The last three built, each of a capacity of 1 m.g., were of circular form and were set on the surface of the ground.

Cost of Operating a Rapid Sand-Filtration Plant.

As there are only a few modern filtration plants in South America within the tropics and as the operating costs are generally not available in detail, or in any form, the data in Table 11 relative to the operation of the plant at Cali, Colombia, are of special interest.

TABLE 11.— AVERAGE MONTHLY COST OF OPERATION AND MAINTENANCE OF THE RAPID SAND-FILTRATION PLANT AT CALI, COLOMBIA, S. A., IN COLOMBIAN CURRENCY (PESOS). NOMINAL CAPACITY OF PLANT, 8.0 M.G.D.

Item.	Year.		
	1932	1933	1934
Chemicals	1 463.10	1 363.28	946.41
Permanent operating personnel	....	711.17	812.56
Extra labor	....	80.28	81.87
Light and power	....	403.05	349.53
Miscellaneous expenses	....	279.14	330.28
Total cost ..... pesos	2 644.16	2 840.94	2 520.67
Cost per cubic meter ..... centavos	.0025	0.032	.0035
Cost per million gallons	9.50	12.11	13.24
Consumption in cubic meters	1 061 000	908 898	706 050

During 7 months of 1934 the payroll of the permanent operating personnel was 833 pesos per month. The members of this force and their wages are shown below. Under the column headed "Normal" the author has entered the wages that will probably be paid during normal conditions but not during "boom" times such as in 1930.

TABLE 12.— WAGES OF OPERATING PERSONNEL OF FILTRATION PLANT, CALI, COLOMBIA, S. A.

Number.	Position.	Wages in Pesos.	
		1934	Normal.
1	Superintendent	170	250
1	Assistant Superintendent	110	190
3	Filter Operators at 68 pesos each	204	270
3	Helpers at 48 pesos each	144	210
1	Mechanic	60	80
1	Assistant Operator and gardener	36	58
1	Laboratory helper	43	58
2	Laborers at 33 pesos each	66	90
13	Total	833	1 206

The extra labor covered the cleaning of the mixing tanks and settling basins; transfer of alum from freight house to plant; cleaning sand in filters; etc. It was practically equivalent to three laborers per month. The light and power covered electricity for lighting and for heating units in the laboratory; and operation of air compressor, wash-water pumps, booster pump for washing settling basins and sand, and agitators in lime tanks. The electrical energy varied from 6 250 to 11 000 k.w.h. per month. The miscellaneous expenses covered apparatus for the laboratory; spare

parts for pumps and chlorinators; garden and fire hose; electric bulbs; soap, etc.; stationery supplies; tools; trucking; etc.

The fixed charges for the filtration plant were not shown in the annual report of the Administrative Board but the average "commercial value" of the filtered water during the year 1934 was calculated as follows:

	Cost per Month; Pesos.
Administration and miscellaneous expenses	2 476.01
Cost of purification	2 520.67
Interest at annual rate of 6 per cent. on value of water works, 1 725 148.54 pesos	8 625.74
Depreciation and amortization at annual rate of 4 per cent. on above value	5 750.49
Total	19 372.91

19 372.91 pesos divided by average monthly consumption of 706 050 cu. meters of water yields 2.74 centavos as the "commercial value" of 1 cu. m. of water or 0.1037 centavos per 1 000 gal.

The average quantities of chemicals consumed per month during 1934 were as follows: aluminum sulphate, 27 850 lb.; lime, 4 872 lb.; and chlorine, 278 lb. A total of 3 100 lb. of soda ash was used in cleaning sand in the filters.

During 1932, the monthly consumption of alum was 47 666 lb., or 19 816 lb. more than were used during 1934. The reduction effected in the consumption of water by meters installed on services of consumers, discussed in detail in a later section of this paper, was responsible for a reduction of 237 800 lb. in the consumption of alum during 1934. At 3 centavos per pound, this reduction represented a saving of 7 134 pesos. To this should be added 184 pesos for the reduction of chlorine, making a total of 7 318 pesos which should be credited to the cost of the installation of meters.

The cost of operating a filtration plant in the tropics is influenced to a relatively large degree by the cost of the materials imported from other countries. The cost is also affected by the rate of exchange, import duties, and freight from the port to the city in which the plant is located.

During 1934, the average monthly cost of operation and maintenance of the Cali plant was 2 520.67 pesos. Of this sum 946.41 pesos were for chemicals from which a deduction must be made for the cost of lime purchased locally. As an average of 4 872 lb. was used per month, the cost, at 1.25 pesos per 100 lb., was 60.90 pesos. Deducting this from 946.41 pesos, the average monthly cost of imported chemicals was 885.51 pesos or 35 per cent. of the monthly cost of operation and maintenance.

The first lot of soda ash, purchased in the United States in April, 1929, cost 2.79 centavos per pound at Buenaventura, the port of entry. The charges for freight, handling, etc., from this port to Cali, a distance of 108 miles, amounted to 1.90 centavos, making the total cost of soda ash

4.94 centavos per pound at the filtration plant. At this time, the peso was nearly equal to the dollar. After the plant had been in operation nearly three years, it was decided to substitute lime for soda ash to reduce the cost of chemical treatment and to use a local product in preference to an imported one. The first lot of alum purchased in the United States in April, 1929, cost 2.62 centavos per pound at Buenaventura and 4.77 centavos landed at the plant in Cali.

The prices of shipments of alum and chlorine purchased at later dates are given in Table 13 in the currencies of the two countries to show the influence of the rate of exchange.

TABLE 13.— COSTS OF ALUM AND CHLORINE AT PORT OF ENTRY AND AT FILTRATION PLANT IN CALI, COLOMBIA, SOUTH AMERICA.

Pounds.	Date of Payment.	ALUM.			CHLORINE.		
		BUENAVENTURA.		CALI.	BUENAVENTURA.		CALI.
		Cents.	Centavos	Centavos	Cents.	Centavos	Centavos
400 000	Jan., 1933	1.53	1.61	2.46	...	...	...
3 750	June, 1933	...	...	...	8.9	11.5	16.1
400 000	Sept., 1933	1.62	2.43	3.17	...	...	...
2 250	May, 1934	....	...	...	7.8	14.0	18.0
200 000	Oct., 1934	1.45	2.25	2.96	...	...	...

The prices in cents are the costs C.I.F. at Buenaventura; the costs in the next column in centavos show the influence of the rate of exchange; the costs in centavos in the column headed "Cali" include the freight, handling charges, etc. to place the chemicals in the plant. Municipal water works in Colombia are exempted from import duties on alum and chlorine but not on other materials; prior to January, 1933, all materials imported were exempted from duties.

The exchange rate in Colombia, in relation to the United States dollar, rose from 105.25 per cent. in the early part of 1933 to 116.25 per cent. in February; 126.25 per cent. in September; 150 per cent, in October and November; and 162 per cent. in December. During 1934, it dropped to 150 per cent.; rose to 185 per cent. in August; and then declined to 155.25 per cent. at the end of the year. The parity is 102.74 per cent.

Table 14 shows the relation between the receipts and expenditures of the water works in Cali, Colombia. In 1933, for the first time during the existence of the municipal water works since 1920, the sum of 21 035.85 pesos, or 1.216 per cent. on a valuation of 1 730 215.39 pesos, was set aside for depreciation. To illustrate what may happen to such a reserve, attention is called to expenditures approved by the municipal council during 1934 which amounted to 38 500 pesos, or the sum which was to be set aside as a depreciation fund in that year for the water works, slaughter-house,

and public market, of which approximately 34 000 pesos were taken from the funds of the water works.

TABLE 14.— RELATIONS BETWEEN GROSS INCOME AND OPERATING EXPENSES OF MUNICIPAL WATER WORKS OF CALI, COLOMBIA, SOUTH AMERICA.

Item.	Pesos. 1933.	1934.
Gross income	184 219.16	192 210.57
Operating expenses	55 793.78	59 840.02
Per cent. of gross income	30.2	31.1
Operating expenses of filtration plant	34 091.29	30 248.06
Per cent. of total operating expenses	61.1	50.5
Per cent. of gross income	18.5	15.7
Net income	128 425.38	132 370.55
Per cent. of gross income	69.8	68.9

PRESENT STATUS OF WATER PURIFICATION.

The movement to improve municipal water supplies in Central and South America, within the tropics, may be said to have started in 1904 when steps were taken to supply Panama City and Colon, in the Republic of Panama, with potable water. However, it was not until the Panama Canal was opened to traffic in 1915 that the modern filtration plants at Mt. Hope and Miraflores in the Canal Zone, became available for inspection by travelers to and from Central and South America. The water supply systems in Panama City and Colon have served as educational exhibits to a large number of visitors during the last 21 years. Without exaggeration, it may be said that these two filtration plants and their products, safe, attractive and satisfying water, have been a great stimulus to the persons directly interested in improving the sanitary conditions in their native countries and an education to all who have visited them.

The following summary of the present status of water supplies in countries in Central and South America, lying within the tropics, has been prepared from data obtained by the author. It is rather difficult to keep in touch with current developments, as there are no publications, common to all the countries, in which items concerning water supplies appear.

Panama. As previously stated, Panama City and Colon, with a total estimated population of 108 000, are supplied with filtered water from rapid sand-filtration plants operated by the Panama Canal. According to an agreement made between the United States and Panama, the water and sewerage systems of these cities will become the property of the latter republic in 1957, providing that certain payments to the United States are made meanwhile. As a result of this arrangement, and the distribution of an estimated population of 480 000 in Panama, about 23 per cent. of the population is supplied with filtered water of satisfactory sanitary quality and safety. Of the remaining population, it is estimated that approximately

40 per cent. is supplied with water from wells, but some of these are not adequately protected against contamination by surface water.

Colombia. Of the countries in Central and South America, lying within the tropics, Colombia is the only one in which notable progress has been made in the purification of polluted municipal water supplies, and there are 8 rapid sand-filtration plants now in operation.

A new water supply system, constructed at a cost of approximately 2 903 000 pesos, was placed in operation in Barranquilla, with an estimated population of 140 000, in July, 1929. The water is taken from the Mag-

FIG. 15.— RAPID SAND-FILTRATION PLANT AT BARRANQUILLA, COLOMBIA, S.A.

This plant, designed by Pearse, Greeley & Hansen, shows what can be done when a municipality has the money to spend on beautification. At lower left is road to raw-water pumping station on the Magdalena River. Nominal capacity, 8 m.g.d.

dalena River and purified by a modern rapid sand-filtration plant with a normal capacity of 8 m.g.d.

A modern rapid sand-filtration plant, constructed at an approximate cost of 530 000 pesos, with a normal capacity of 8 m.g.d., was placed in operation in Cali in November, 1930. The source of raw water is the Cali River. The population of the city is now about 100 000.

A new water supply system, constructed at an approximate cost of 378 836 pesos, was placed in operation at Buenaventura, with an estimated population of 12 000, in July, 1934. The water is taken from the Dagua River and is purified by a modern rapid sand-filtration plant with a normal capacity of 2.3 m.g.d.

The surface water supplies of five other municipalities, Popayan, Cartago, Pereira, Tulua, and Chiquinquira, with populations ranging from 25 000 to 50 000, are purified by rapid sand-filtration plants. The con-

struction of a rapid sand-filtration plant for the water supply of Santa Marta, an export port for bananas, with a population of about 20 000, will be started soon. A new water supply system, including a 24-m.g.d. rapid sand-filtration plant, is under construction at Bogota, the capital, with a population of 280 000.

Of the total population of Colombia, about 8 400 000, the author estimates that 4 per cent. is supplied with filtered water of satisfactory sanitary quality and safety, and that 6 per cent. of the remaining population is supplied with water treated with chlorine.

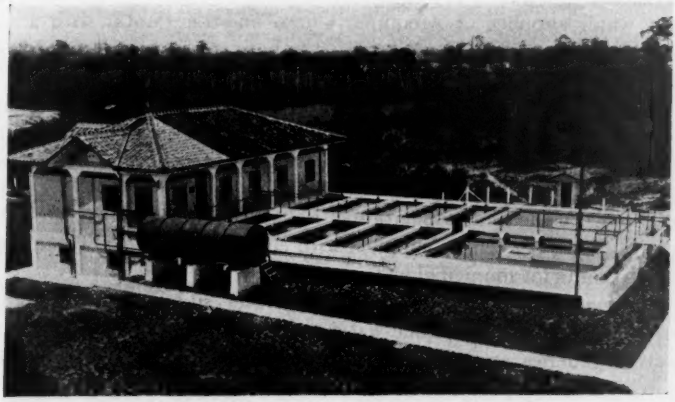

FIG. 16.— RAPID SAND-FILTRATION PLANT AT BUENAVENTURA, COLOMBIA, S.A.

From left to right: filter building, air tank, and settling basins. Nominal capacity, 2.3 m.g.d. Lobo Guerrero & C. S. De Santamaria, engineers and constructors.

Venezuela. Very little progress has been made in the purification of the water supplies of the principal cities. None of the supplies are filtered, and at the present writing none are chlorinated. A trial of the Verdunisation system was made recently on the water supply of Caracas, the capital. The author has been advised that the trial was an expensive one and that treatment was stopped because the results were unsatisfactory. Typhoid fever and dysentery are endemic in many sections of the country, and according to reports published by protozoölogists a very large proportion of the inhabitants are carriers of intestinal parasites.

Ecuador. A new water supply system, including a slow sand-filtration plant, was constructed a few years ago in Guayaquil, the principal port of the country with an estimated population of 100 000, at an approximate cost of $2 500 000. The normal capacity of the plant is 5.25 m.g.d. It is reported that the consumption of water is equal to the capacity of the plant. There are no other filtration plants in the country. The water

supplies of Quito, Ambato, and Tulcan, with an estimated total population of 150 000, are reported to be chlorinated. The author estimates that 4.5 per cent. of the total population of Ecuador, approximately 2 900 000, is supplied with filtered and chlorinated water, and that 6.0 per cent. of the remaining population is supplied with chlorinated water.

Peru. Very little progress has been made in Peru in the purification of municipal water supplies. Talara, with a population of about 8 000, is the only community supplied with filtered and chlorinated water from a modern rapid sand-filtration plant. It is the principal port for the exportation of oil. The water supplies of Lima and the suburbs, Callao, Chosica and Huacho, with a total population of about 391 000, are chlorinated. The ground water supplies of Arequipa, Cuzco and La Punta, with a total population of about 88 000, are reported to be of good sanitary quality and safety. Including Talara, the author estimates that 7.5 per cent. of the total population of Peru, about 6 500 000 is supplied with chlorinated water.

Bolivia. Very little progress has been made in Bolivia in the development of public water supplies of safe quality. It is reported that the water supply of La Paz, the capital, with a population of about 150 000, is chlorinated. Of the total population of Bolivia, about 2 800 000, the author estimates that 5 per cent. is supplied with chlorinated water. There are no filtration plants for municipal water supplies.

Nicaragua. None of the municipal water supplies in Nicaragua is filtered. Up to 1928, the public water supply of Managua was taken from collecting galleries and shallow wells near the shore of Lake Managua. The well water was polluted by the numerous cesspools in the city. During 1924, the disinfection of the water supply by chlorine was started in order to reduce the cases and deaths from water-borne diseases.

In 1928, work was started on a new water supply by R. W. Hebard & Co., New York City. Lake Asososca, covering an area of 240 acres, with a minimum depth of 900 ft., and located only 2 miles west of Managua, was selected as the source of the new water supply. The water was lifted about 300 ft. through a 12-in. spiral-welded pipe line to a concrete distributing reservoir from which it flowed by gravity to the distribution system through a 12-in. cast-iron pipe line and gave a hydrant pressure of 50 to 75 lb. per sq. in. The water was chlorinated at the pumping station.

A new distribution system of cast-iron pipes, varying from 4 to 12 in. in diameter, was laid over about one-third of the total area of the city before the work was stopped by the Government in 1930 due to the financial depression. Sanitary and storm-water sewers and paving were completed in the same area. As stated in a preceding section of this paper, the pumping station was damaged by an earthquake but was replaced in service about 20 days later.

According to Magoon,[35] at the end of 1933, about 2 000 of the houses in Managua were connected to the public water system, but as there were no meters on the services, the waste of water was high; possibly about 2 000

more houses obtained part of their water from this system; and the remaining 5 000 houses received water from dug wells of uncertain sanitary quality. The city is located over a porous volcanic subsoil pierced by many subterranean streams of water, and it is expected that an additional supply of water of good quality may be obtained from this source at a relatively low cost for many thousands of people who now use water of questionable quality.

It is reported that the water supplies of Leon and Granada are chlorinated. Of a total population of about 800 000 in Nicaragua the author has estimated that chlorinated water is available to about 10 per cent. During the past years, there have been several suspensions in the operation of the chlorinators which gives the impression that chlorination has not been taken very seriously by the personnel of the water works.

Salvador. During the years 1924 to 1929, inclusive, the Government contracted with R. W. Hebard & Co., New York City, to undertake the sanitation of San Salvador, the capital, with a population of about 100 000, and of the port of La Libertad with a population of about 2 000. In both communities, the work included sanitary and storm sewers, a water distribution system, the paving of streets, and sidewalks. The total cost of the work was approximately $4 500 000 which included some special works not related to sanitation.

A small modified slow sand-filtration plant, with a capacity of 100 000 g.p.d., was installed in La Libertad for purifying a river water supply. The plant included an ultra-violet ray sterilizer. After the plant had been in service for some time, it was found necessary to clarify the raw water with alum in order to obtain filtered water of satisfactory quality. It appears that the principal difficulty at this plant arose from the failure of the Government to provide competent personnel for its operation.

The water supply of San Salvador is derived from springs and, according to latest information, is chlorinated. It is reported that the water supply of Santa Ana, with a population of about 72 000, is also chlorinated. Of the total population of Salvador, about 1 500 000, the author estimates that chlorinated water is available to 7 per cent.

Honduras. It is reported that the public water supply of Tegucigalpa, the capital, with a population of about 40 000, is chlorinated. There are no filtration plants for municipal water supplies.

Guatemala. It is reported that the water supply of Guatemala City, the capital, with a population of about 140 000, is chlorinated. There are no filtration plants for municipal water supplies. The author estimates that chlorinated water is available to 6.0 per cent. of the total population, about 2 200 000.

Costa Rica. Due to the excessive waste of water in San Jose, the capital, with a population of about 60 000, the supply of ground water is supplemented by river water which is purified by sedimentation, slow sand-filtration and chlorination, with the result that it is of satisfactory sanitary

quality and safety. The services are metered to the extent of 15.2 per cent. (November, 1935).

The water supply of Limon, the port on the Atlantic side, with population of about 15 000, is taken from a river and passed through settling basins but is neither filtered nor chlorinated. The water supply of Cartago, taken from springs, is of satisfactory sanitary quality at the source but is subject to contamination before it enters the distribution system.

Of the total population of Costa Rica, about 530 000, the author estimates that chlorinated water is available to 9 per cent. Little progress has been made in the development of municipal water supplies of satisfactory sanitary quality.

Conveyance and Distribution of Water.

Intakes in rivers and creeks are generally placed back of what may be called a submerged weir across the stream which may be built of stone blocks, concrete, or more often of boulders and gravel. If a flood sweeps away such a weir, one of the more primitive type is the more easily rebuilt. Occasionally a dam is built on a small river and provided with a sluice gate through which water is discharged during floods. Such dams are seldom longer than 25 ft. and higher than 10 ft.

From the intake, the water is generally conveyed to a storage and distribution reservoir of small size through an open unlined canal or a pipe line of steel; rarely through one of cast-iron pipe. The first cost of a canal, usually unlined, is less than that of a pipe line, but the cost of maintenance of a canal over a long period of time is high, and slides on a hillside often cause breaks in such canals. Furthermore, the water running through a canal receives more or less pollution from surface drainage.

In many cases, the water is run directly into the distribution system, passing only through coarse bar screens and a small chamber to catch the fine gravel and coarse sand. During flood stages of a stream, more or less fine sand is swept into the distribution system and erodes the steel mains. Air often enters the supply main along with the water and causes a severe hammer which occasionally breaks a street main.

Measurements of the volume of water entering the distribution system are made with weirs, if they are made. Weirs are usually installed to govern the operation of chlorinators. Venturi meters are seldom used until filtration plants are built or chlorinators are installed but not often for the latter.

In some of the earliest water works, the water was distributed through open channels in the streets which also served as drains for slops, etc. Such systems still exist in the small communities which do not have sufficient funds for a distribution system of pipes. Under these conditions, it is advantageous to live near the upper end of the canal. Earthen-ware pipes were used in some of the early installations and are still in service in some of the smaller cities.

Occasionally, in cities far away from the seaports, cast-iron pipes of very fair quality were manufactured but not to any great extent. Later on steel and cast-iron pipes were imported with preference given to the former by interior cities to reduce the weight, transportation charges, and breakage. Mannessmann steel pipe has been imported to a considerable extent and is an active competitor of pipe made in the United States. A considerable amount of Pont-a-Mousson cast-iron pipe has been imported, but the breakage has been high due to the high phosphorus content.

Black iron, and later, galvanized-steel pipe, with much of the latter imported from Germany with defective galvanizing, are used for services.

FIG. 17.— UPPER INTAKE ON CALI RIVER, CALI, COLOMBIA, S. A.

Taken during low-water stage with dam of boulders and gravel built to deflect water to intake and thence into open canal that conveys raw water to filtration plant.

On the author's advice some brass pipe and copper tubing have been installed in a few cities where the life of other pipe has been short due to soil corrosion. The author believes that more pipe of these materials may be sold while the price of copper is low, if the proper sales efforts are made and if the rate of exchange is normal.

The majority of house services are of ¼-, ⅜-, and ½-in. pipes. In some cities, in the older houses, the service pipe is run through the front door, the hall, and the patios and thence laid on the floor until the kitchen is reached. The governing factor in service installations is low first cost to consumers.

Corporation cocks, lead goosenecks, and tapping machines were not used to any extent until a few years ago when they were introduced by engineers from the United States or by plumbers from the Canal Zone in

revamping distribution systems. In the interior cities, lead goosenecks are seldom used, and in many cities corporation cocks are not used.

In the more progressive cities, especially those in which concrete pavements are being laid, the street mains are laid at a depth of 2 to 3 ft., but in the smaller cities they are often laid at a depth of 1 ft. or less.

Nearly all of the public water supplies are owned and operated by the municipalities. In the majority of cities, meters are not in use. Here again the cost is one of the principal obstacles to be overcome, while the principal argument against metering is that poor people will not receive enough water for hygienic purposes. The author knows of two cities in which the meters first installed were torn out by groups of consumers who were opposed to their use.

There are always members in every municipal council who appoint themselves as saviors of the poor people to further their political interests. For this reason they will be found as opponents to the introduction of meters. It is only when a city suffers a shortage of water or when a filtration plant is built that meters are seriously considered and installed.

After meters have been in service for about one year, the majority of the consumers are not only satisfied with the purchase of water by meter but prefer it to the old flat-rate system. If a city is situated near a large river with an abundant flow of water at all times, it is very difficult, and sometimes not politic in view of local conditions, to meter the services. The inhabitants will oppose the installation of meters but do not object to spending money on additions to the water system to maintain a high per capita consumption resulting from excessive waste.

Unless the city is of small size, with a population of 15 000 or less, and the government is furnishing the funds for a new water system, the installation of meters must be spread over several years, as a municipality rarely has the funds to purchase the total number of meters required during one year, or two years, and to bear the expense of their installation. If the exchange rate becomes very unfavorable, the cost of meters is increased and their purchase is either stopped or a smaller number is ordered.

Figure 18 shows the effectiveness of meters in reducing the consumption of water in Cali, Colombia. A modern rapid sand-filtration plant was placed in service in November, 1930. In his first report to the manager of the water works in October, 1927, the author recommended the metering of all services before filtered water became available to reduce the great waste of water, but this recommendation was not adopted. The capacity of the filtration plant was based on a per capita consumption of 66 gal. (250 liters) with all services metered. By September, 1932, the average daily consumption had increased to 36 346 000 liters and the maximum daily consumption to 38 662 000 liters. As a result, the nominal capacity of the filtration plant, 30 283 000 liters per 24 hours (8 m.g.d.) was exceeded, and throughout 1932 it was necessary to add each month from 3 to 9 per cent. of settled water to the filtered water in order to meet the consumption

although the plant was operated at 10 per cent. above capacity. House-to-house inspections to control the waste and leakage were tried, but they were ineffective in reducing the consumption due to certain local conditions.

Finally it was decided to adopt the author's original recommendation to meter the services, and work was started in April, 1933. In May, with 17.8 per cent. of the services metered, the reduction in consumption was sufficient to stop the addition of settled water to the filtered water. At the end of September, 41 per cent. of the services in use had been metered, and the average daily consumption of water had been reduced 31 per cent. as compared with the consumption in March. At the end of December,

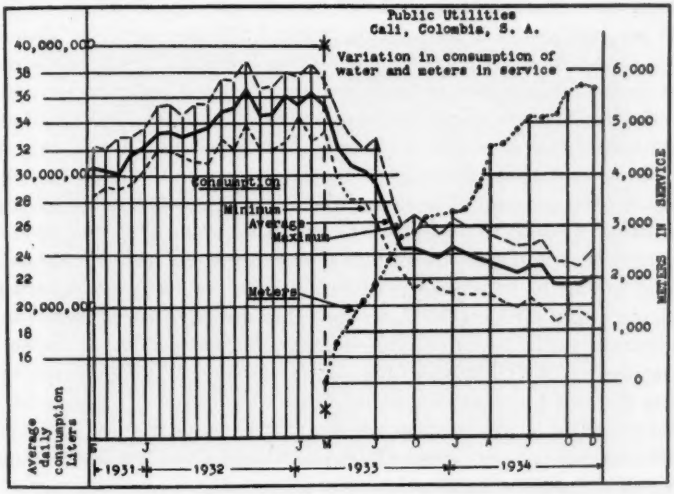

FIG. 18.— RELATION BETWEEN METERS IN SERVICE AND CONSUMPTION OF WATER IN CALI, COLOMBIA, S. A.

45.5 per cent. of the services in use had been metered, and the average daily consumption of water had been reduced 33 per cent. as compared with March, and there were 331 additional services in use.

The installation of meters was continued through 1934 but, due to the unfavorable rate of exchange, the total number installed was less than during 1933. At the end of October, 1934, 69.6 per cent. of the services in use had been metered, and the average daily consumption of water had been reduced 45.3 per cent. as compared with March, 1933. During November and December the average daily consumption increased slightly with the result that during December it was 22 024 000 liters, or 38 per cent. less than it was during March, 1933. At the end of December, 1934, 71 per cent. of the services in use were metered and there were 636 more services in use than at the end of December, 1933, and 967 more services

than at the end of March, 1933, when the installation of meters was started.

At the end of August, 1935, 80.5 per cent. of the 8 420 services in use had been metered; there were 640 more services in use than at the end of December, 1934; and 1 607 more services than at the end of March, 1933. The average daily consumption during August, 1935, was 19 839 000 liters or 44 per cent. less than it was in March, 1933, when the installation of meters was started. Notwithstanding the 640 services added during the first 8 months of 1935, the average daily consumption during August was 2 657 000 liters less than during August, 1934, and 2 185 000 liters less than during December, 1934.

Of 6 996 metered services at the end of August, 1935, 96.88 per cent., were in use. There remained 1 642 flat-rate services of which 1 549, or 94.34 per cent., were in use. Of the latter 1 332 were of ⅜-in. diameter; 207 ½-in.; and 6 ¾-in. The manager of the water works intends to meter all of the flat-rate services as funds become available for purchasing meters.

The benefits resulting from the reduction in waste and leakage of water by the installation of meters in Cali were as follows: the addition of at least two filters, and probably four, to the filtration plant was postponed indefinitely; the addition of settled water to the filtered water was stopped; the cost of chemical treatment of the water was reduced, (*a*) by reduction in consumption and (*b*) by being able to shut down the plant during periods as long as four hours when the turbidity of the raw water was very high following heavy rains on the water-shed and supplying filtered water to the distribution system from the storage reservoir; an increase in pressure in the central section of the distribution system from 30 to 60 lb. per sq. in. during the daytime; operation of the filters at normal rate; maintenance of sufficient water in the storage reservoir with seven filters under normal conditions thus permitting one filter to be cut out of service for cleaning the upper three inches of sand or for other purposes.

On the assumption that the population of Cali was 90 000 at the end of 1934, the per capita consumption of water per day was approximately 64.5 gal. (244 liters). During the last months of 1934, the total volume of water supplied through meters was approximately 320 000 000 liters per month. The manager of the water works estimated that 60 000 people out of a total population of 90 000 were supplied with water through meters and that the daily per capita consumption was 43.8 gal. (177 liters).

On this basis the daily per capita consumption of the remaining 30 000 people approximated 94 gal. (356 liters). This latter figure includes leakage from the distribution system, water used for public purposes, and leakage and waste from fixtures in houses supplied on a flat-rate basis. In December, 1934, there was a total consumption of 45 844 000 liters of water through 89 services in public schools, municipal hospitals and buildings, the market, slaughter-house, parks, public fountains, etc. to which filtered water was supplied free of charge. The average consumption per

service was high, 515 000 liters per month, or approximately equal to that of the metered industrial services.

It is probable that the combined leakage from all the service pipes of the distribution system is relatively high, as the life of galvanized steel pipe in the soil of Cali is 5 to 6 years. During 1933, it was necessary to replace 514 services with new ones for which brass pipe or copper tubing was used. During 1934, the use of brass pipe was discontinued, and copper tubing was used for only 50 per cent. of the services on account of its high first cost as compared with galvanized-steel pipe. If the rate of exchange had not been so unfavorable, it is probable that more copper tubing would have been used.

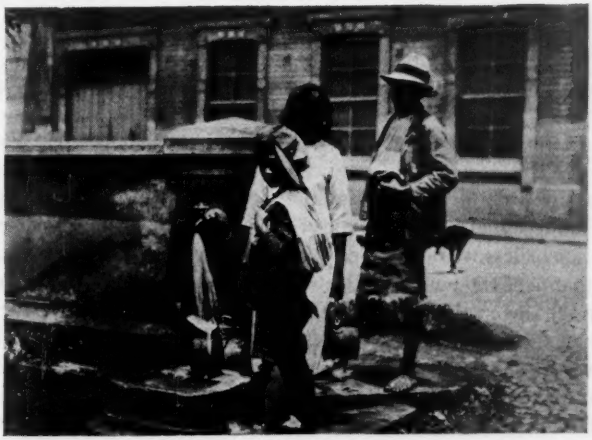

FIG. 19.— PUBLIC FOUNTAIN FOR FURNISHING WATER TO POOR PEOPLE.

The cost of installation of 6 254 meters during 1933 and 1934 totaled 104 919 pesos. This covers meters, concrete meter boxes made locally, necessary connections and labor. A credit of 7 138 pesos should be applied to this cost as representing savings effected in alum and chlorine during 1934 by reduction in consumption of water.

The cost per meter averaged 15 pesos during 1933, of which 2.19 pesos were for labor and 12.81 pesos for the meter and other materials. During 1934, these figures increased to 21.21, 2.87, and 18.34 pesos, respectively. The average cost of a meter and other materials used in an installation ranged from a minimum of 8.65 pesos in May to a maximum of 20.77 pesos in December, 1933; and from a minimum of 16.78 to a maximum of 22.10 pesos in 1934. The large increase in 1934 was due to three factors: increase in price of meters in the United States; rise in rate of exchange; and addition of import duties that were not charged formerly. If the cost of installation per meter had remained at 13.63 pesos during 1933 and 1934 a

saving of 19 677 pesos would have been effected in the installation of the 6 254 meters.

The meter rates in Cali, Colombia, are as follows for the three classes of services which have been established:

First Class. Factories, hotels and cafes of the highest grade, office buildings or apartments, and industrial establishments according to the opinion of the Board of Administration or of the Manager of the Water Works: 5.00 pesos per month with the right to 100 000 liters (26 418 gal.) of water.

Second Class. Residences valued at more than 1 000 pesos; hotels, cafes and factories of second grade; apartments, important stores and private schools: 2.00 pesos per month with the right to 60 000 liters (15 850 gal.) of water.

Third Class. Houses valued at 1 000 pesos or less; small apartments and shops: 1.20 pesos per month with the right to 45 000 liters (11 880 gal.) of water.

These charges are considered as the minimum charges and must be paid whether or not the specified volumes of water are consumed. If the consumption exceeds the volumes specified the services of the First Class will pay 4 centavos per 1 000 liters (264 gal.) for the first 100 000 liters (26 418 gal.) in excess and 3 centavos for each 1 000 liters above the latter amount. Classes 2 and 3 will pay at the rate of 3 centavos for each 1 000 liters in excess of the specified allowance per month.

NOTE: At parity 1 peso equals 0.9732 United States dollar; in August, 1935, the rate of exchange was such that 1.77 pesos equalled 1.00 dollar.

A comparison of the rates for the second and third classes shows that a slight reduction is made in favor of the occupants of houses of low value, 1 000 pesos or less, with the idea that their incomes are less than those of the occupants of the houses in the Second Class. This difference in rates is based on the theory that occupants of expensive houses should pay more for water than those of cheaper houses. This is a common method of favoring the poorer people in South American cities.

The first set of meter rates specified a maximum allowance of 50 000 liters (11 320 gal.) for services of the Second Class and of 36 000 liters (9 510 gal.) per month for services of the Third Class. As a result of protests made by some of the people in these classes that the rates were excessively high and the maximum allowances were too low, the municipal council, contrary to the recommendation of the Board of Administration, increased the allowances for the second and third classes to 60 000 and 45 000 liters, respectively.

During 1934, the average monthly metered consumption per service of the Second Class exceeded 50 000 liters only during one month, the excess amounting to only 190 liters, and during the other 11 months it ranged from 46 630 to 49 910 liters. The average metered consumption per service of the Third Class never reached 36,000 liters in any month, the highest monthly consumption being 27 600 liters and the lowest, 20 490 liters; the average metered consumption per service of the First Class exceeded the allowance during each month, ranging from 446 630 liters in January, with 143 meters in use, to 520 830 liters in December, with 178 meters in use.

From these figures, it is evident that the allowances of 50 000 and 36 000 liters per month, originally established for the second and third

classes, respectively, were high enough and met the legitimate needs of both classes of consumers. The argument that the poor people would not have sufficient water for hygienic purposes was proved to be entirely wrong, as they never used the entire allowance even during the warmest months.

The danger of increasing the allowance lies in the fact that it may be set so high that meters no longer serve to reduce the waste of water but only serve as chambers through which the water passes. It is interesting in this respect to note that the average monthly metered consumption through services of the Third Class increased from 20 490 liters, with 750 meters in use in January, 1934, to 25 570 liters, with 2 088 meters in use in December, 1934, an increase of 5,080 liters; and to 30 750 liters, with 2 966 meters in use in August, 1935, which made the second increase of 5 000 liters in the consumption of water by this class during the 8 months of 1935.

The average monthly metered consumption through services of the Second Class increased from 46 630 liters, with 2 420 meters in use, to 49 910 liters with 3 271 meters in use in December, 1934, an increase of 3 280 liters; and to 53 470 liters, with 3 527 meters in use in August, 1935, which made a second increase of 3 560 liters in the consumption of water by this Class during the 8 months of 1935.

It is feared by those who are interested in reducing the waste of water by consumers that, as time goes on, they will gradually increase their consumption to the total of the allowance for each class as they learn that it is unnecessary to be so careful about closing faucets immediately after drawing water for legitimate purposes. This procedure has been aptly termed "hunting" for the maximum allowance of water. The remedy lies in reducing the allowance of water for each class, or setting it at a volume that experience shows is ample for legitimate purposes, but this is difficult because members of the municipal council will be threatened with loss of votes and results unfavorable to their political future. The author has found that the allowance of water for metered services in other cities in the tropics has been set so high that meters have failed to reduce the waste of water by consumers.

Impounding Reservoirs in the Panama Canal Zone.

As previously stated, the first water supplies for the employees of the Panama Canal and the inhabitants of Colon and Panama City were taken from four impounding reservoirs with capacities as shown in Table 15.

Contrary to the expectations of the author when he went to the Canal Zone, relatively little trouble was experienced with disagreeable tastes and odors from algæ in the reservoirs. At times when odors of any noticeable intensity developed, aëration of the raw water, if properly carried out so as to break up the water into spray, successfully removed them, and it was never necessary to apply copper sulphate to Brazos Brook and Agua Clara reservoirs to eliminate odor- and taste-producing microscopic organisms during the period of 1914 to 1927.

Copper sulphate was used successfully in these reservoirs to reduce the numbers of certain organisms which were influencing the length of filter runs, but the author came to the conclusion that no great saving in cost of operation was effected by the treatment when the cost of the latter was balanced against the cost of wash-water saved.

TABLE 15.— DATA RELATING TO IMPOUNDING RESERVOIRS IN THE PANAMA CANAL ZONE.

Name.	Supplied Water to.	At Maximum Water Level.			
		Elevation Above Sea Level.	Volume of Water; m.g.	Catchment Area; Acres.	Area of Water Surface; Acres.
Brazos Brook	Mt. Hope filtration plant.....	49.5	650	896.7	156.0
Agua Clara	Agua Clara filtration plant....	68.0	612	1 019.5	69.5
Rio Grande	West side of Canal.....	235.0	400	2 015.5	62.0
Camacho	West side of Canal.....	365.0	280	592.0	34.3

During the year ended June, 1917, the means of the weekly determinations of microscopic organisms in the raw water flowing from Agua Clara Reservoir to the filtration plant varied from 76 to 677; the maxima from 122 to 820; and the minima from 28 to 320 standard units per c.c. The means of the determinations of amorphous matter varied from 387 to 6 008; the maxima from 544 to 10 880; and the minima from 228 to 3 696 standard units per c.c.

The diatomaceæ, and fungi and schizomycetes were present in noticeably smaller numbers than other classes, 1.7 and 0.5 per cent. respectively, of the total organisms. Cyanophyceæ and rotifera were somewhat more abundant but relatively scarce, 5.8 and 8.1 per cent., respectively. Chlorophyceæ and crustacea were found in about equal numbers, each nearly 20 per cent. of the total organisms. Protozoa occurred in much larger numbers than any of the preceding classes, amounting to 43 per cent. of all organisms found. Of these *Peridinium*, *Glenodinium* and *Dactylosphærium* occurred in greatest abundance, especially the first.

In the case of Camacho and Rio Grande reservoirs, from which water supplies were taken without filtration for the communities and army posts on the west side of the canal, it was necessary to appply copper sulphate several times to remove excessive growths of *Anabæna*, *Peridinium* and *Glenodinium* which produced offensive odors. Camacho Reservoir, during a period of three years, was distinguished by the rapid growth of *Chlamydomonas* and *Peridinium* in sufficient numbers to add a noticeable turbidity and a greenish or brownish tint to the water.

During 1915, when water from the eastern arm of Miraflores Lake was passed through pressure filters, without preliminary sedimentation, extremely sudden and large growths of diatoms developed at intervals of a few weeks, with the result that in a few hours the filters were plugged tight

and large quantities of wash water had to be used until copper sulphate could be applied to reduce the diatoms. At such times, there was always a struggle to maintain enough filtered water in the distribution reservoir due to short filter runs and high consumption of wash water.

The influence of microscopic organisms on the length of filter runs was also demonstrated at the Miraflores filtration plant. The longest runs of about 141 hours were obtained during the flood stages of the Chagres River during the rainy seasons. As the turbidity of the raw water decreased after the floods, microscopic organisms started to increase in numbers and the filter runs to shorten. The shortest runs, about 15 hours, occurred during the dry seasons. It was found that an increase in alum dosage effected a partial removal of the organisms in the settling basins and increased the length of filter runs.

Abundant growths of *Spirogyra* formed on the walls and bottom of the uncovered sedimentation basins of the Miraflores plant, which measured 125 by 300 ft. in plan by about 16 ft. in depth, and held approximately 4.5 m.g. of water. The detention period was 12 hours, theoretically.

The greatest growth of *Spirogyra* occurred on the bottom of the sections at the outlet end of the basins, although long filaments were attached to ladders, walls and baffles. There was also a growth on the skimming platforms at the outlet end. On many days, especially during the dry season, the water was clear enough in the sections at the outlet end to see the floor of the basin. The water was aërated before it entered the basin, the dissolved oxygen ranging between 90 and 100 per cent. of saturation at the outlet end, so that neither this factor nor poor circulation could account for the luxuriant growth on the floor of the basin. Similar growths were not observed in the basins at the Mt. Hope and Agua Clara plants.

A mat of algæ, mixed with floc, covered the upper part of the walls and the troughs on the transverse baffles. Pieces of this mat broke off frequently and were carried in the settled water to the filters.

The time required for cleaning the basins was lengthened considerably and made more difficult by the necessary removal of the mat of algæ and *Spirogyra* from the walls and floor, as they adhered quite tenaciously to the concrete surface. For several years, the basins were cleaned at intervals of about 4 weeks because pieces of sludge broke loose from the floor of the sections at the inlet end and were carried to the surface by entrained gas bubbles produced by fermentation set up in the sludge.

There was also a luxuriant growth of algæ in the raw-water aëration basin on the walls, floor and lines of pipes on which the nozzles were set. This basin was cleaned each time the settling basins were cleaned. The tenacious and slippery nature of the coating of algæ made the cleaning a long and tedious job. Steel hoes were used at times to scrape the mat of algæ off the floor, and brushes were employed on the pipes. Application of a strong lye solution helped in the removal of algæ from the floor, but made it very slippery for the men.

Notwithstanding the luxuriant growth of chlorophyceæ in the basins and the presence of considerable numbers of diatoms in the Chagres River during the dry seasons, there never occurred, prior to 1928, a development of microscopic organisms that produce offensive odors and tastes in reservoirs in the United States. With the completion of the new Madden Dam on this river, located above the intake of the water supply for the Miraflores plant, it will be interesting to observe how the odor and taste of the water supply will be affected by the foul water which will be discharged from the new impounding reservoir and by the organisms which will develop in it.

Occasionally, odor- and taste-producing organisms developed suddenly in the arm of Gatun Lake from which the water supply for the Darien Radio Station was pumped. The remedy consisted in lowering the intake from its customary location near the surface to a deeper stratum of water and then applying copper sulphate.

The low-service distributing reservoir for Panama City remained free from troublesome algal growths from 1905 until 1919–1920 when vigorous growths of *Mougeotia* suddenly appeared and developed into such a nuisance, not only to the consumers but to the maintenance force as well, on account of the frequent cleanings which were required, that it was covered.[34]

Contrary to the studies of some other tropical waters, diatoms in the reservoirs, lakes, and rivers on the Isthmus of Panama are relatively abundant. Table 16 shows the relative abundance of diatoms in relation to the total number of standard units of diatomaceæ, chlorophyceæ, cyanophyceæ, protozoa, fungi and schizomycetes, rotifera and crustacea which were found in 358 samples of water collected from the Chagres River, Brazos Brook, Agua Clara, Camacho, and Rio Grande reservoirs and Gatun Lake.

TABLE 16—RELATION OF STANDARD UNITS OF DIATOMS TO TOTAL STANDARD UNITS OF ALL CLASSES OF ORGANISMS DURING YEAR ENDED JUNE 30, 1916.

Source of Sample.	Total Standard Units of All Classes, per c.c.	Standard Units of Diatoms, per c.c.	Per cent. of Diatoms.
Chagres River arm of Gatun Lake	17 419	11 967	68
Reservoirs:			
Brazos Brook	6 778	247	3.6
Agua Clara	7 136	108	1.5
Camacho:			
Surface	79 107	48 390	61.0
Subsurface	121 634	94 182	77.0
Rio Grande	15 293	5 546	36.0
Gatun Lake:			
At Frijoles[1]	10 588	7 938	75.0
At Monte Lirio[2]	3 330	897	27.0

[1] One sample per month during 11 months.
[2] One sample per month during 12 months.

Of the 20 genera of the class Diatomaceæ that were identified, *Nitzchia* was predominant, amounting to from 67 to 99 per cent. of the total number of standard units found with the exception of Agua Clara Reservoir. The small numbers of diatoms in Brazos Brook and Agua Clara reservoirs offered a striking contrast to those in the other sources of supply. While sufficient data are not available to permit a conclusive explanation, the chemical characteristics would indicate that differences in composition of the waters of the various supplies were partly responsible for the variations in numbers of diatoms. Silica, alkalinity, calcium, magnesium, and total mineral matter were present in noticeably smaller amounts in Brazos Brook and Agua Clara reservoirs.

Protozoa made up from 12 to 37 per cent. of the total standard units of all classes of organisms found during the year ended June 30, 1916. Of the 27 genera identified *Glenodinium* and *Chlamydomonas* were present in the greatest relative abundance. Of the other 25 genera *Peridinium* was the predominant form. Cyanophyceæ made up 14 and 15 per cent., respectively, of the total standard units of all classes of organisms found in Brazos Brook and Agua Clara reservoirs but only 1.3 to 4.8 per cent. of the total units in the other reservoirs and in the Chagres River arm of Gatun Lake. There was no one predominant form. Chlorophyceæ made up 17, 32, and 19 per cent., respectively, of the total standard units of all classes of organisms found in Brazos Brook, Agua Clara and Rio Grande reservoirs but only 2.8 to 8.0 per cent. of the total units in Camacho reservoir and the Chagres river arm of Gatun Lake. Of the 29 genera identified, *Protococcus* and *Staurastrum* were present in greatest relative abundance. Filamentous desmids were not as abundant as in some other tropical waters.

Stagnant layers of water with high color and iron and disagreeable odors were frequently found 10 ft. below the surface of some of the reservoirs, and at times even closer to the surface. A water supply of satisfactory appearance and quality cannot be obtained from an impounding reservoir located in the lowlands of the tropics, unless it is aërated and filtered, on account of stagnation and putrefaction of the water at depths of 10 to 13 ft. below the surface.

While it is advisable to equip reservoirs in temperate climates with floating intakes so that the water may be drawn from any desired level, it is absolutely necessary in the case of reservoirs located at low altitudes in the tropics to install an adjustable intake in place of a series of fixed intakes located so as to draw water from only three points, i.e., the surface, middle and bottom. In lieu of an adjustable intake, the next best type is a battery of intakes extending from the surface to the bottom of the reservoir and set as close together as is practicable so as to obtain considerable flexibility. It must be borne in mind that fixed intakes do not permit the withdrawal of water entirely from the plane of their elevations, but some water above and some below, in fact water from all around the intake, will be drawn into it.

Adjustable intakes are especially essential if the water is not to be subjected to purification other than that of storage in the reservoir. Even if a reservoir is to be used as a source of raw water for a purification plant, it is advisable to have considerable flexibility in the withdrawal of the water in order to avoid throwing an excessive load on an aërator.

All reservoirs in the tropics should be provided with blow-off valves in order to waste the bottom stagnant layers of water after heavy rains rather than allow the fresh run-off to waste over the spillway. The poor quality of water in Agua Clara Reservoir during several years was due largely to the non-removal of stagnant bottom water during the rainy seasons. At Rio Grande Reservoir a blow-off siphon[36] was installed to take the place of the blow-off valve, covered over during the construction period, and has worked very successfully.

While the four impounding reservoirs on the Canal Zone were kept in service, a caretaker, at each one, directed the work of a maintenance gang which cut the grass around the shore line, cleaned the beds of the feeders, cleared off the brush and trees growing along the latter and the shore line of the reservoir proper, and took care of the miscellaneous work which developed from time to time. Daily records of the rainfall and elevation of the water were kept.

In the case of reservoirs in which there was a comparatively small variation in the water level, a large share of the gang's time could be devoted to clearing and cleaning the feeders, but in the case of others, the gang was engaged in grass cutting during the greater part of the year. Most of the grass cutting was done by machetes, as the majority of laborers were accustomed to their use, and the roughness of the ground precluded the use of scythes. At Rio Grande Reservoir, where a larger amount of grass was cut than at any of the other reservoirs, scythes were used over the greater part of the shore area, but it was first necessary to smooth the ground by removing stumps and small rocks. Where the topography of the ground was suitable, and it was necessary to cut large amounts of grass, the work was done much faster and cheaper by scythes.

During the dry season, the grass was burned but during the wet season, it was allowed to accumulate until the dry season. Where there was a comparatively small variation in the water level of a reservoir, it was preferable during the wet season to only cut a strip along the shore line sufficiently wide to keep the grass of more than 3-in. height out of the water in case the water level rose 6-in. or so, because it was impractical to burn the grass, and consequently it soon started to decay, and the rains washed the organic matter into the reservoir.

In the case of a reservoir in which there was a drop of 25 ft. in water level in six months and the lowest level was reached during the rainy season, it was necessary to keep the grass cut short over the whole of the exposed shore area in order to be prepared for a sudden rise in water level after a heavy rain. The amount of organic matter added to the water by rains

percolating through the piles of cut grass was far less than that added through the flooding of several thousand square feet of grass a foot or so high.

A larger amount of grass cutting was done around the shore line of Rio Grande Reservoir than at any of the other three reservoirs. The square feet cut during a year varied from about 159 000 to 451 000. The cost of cutting and disposing of the grass averaged 0.07 to 0.08 cent per square foot; this was increased to 0.22 cent when grass standing in water along the shore line was cut by men standing in boats.

The banks of a considerable number of feeders were cleared over a distance of 50 to 75 ft. on either side, which was considered as the minimum for permanent improvement and the elimination of a large number of leaves. The trees and undergrowths were burned after they had dried sufficiently. It was necessary to clean the dry beds of the feeders several times during the dry season to prevent a large number of leaves from being washed into the reservoir at the start of the rainy season. The old deposits of rotten leaves and vegetation were removed from all the pools which, if not too large, were filled with rocks to eliminate the growth of algæ and sources of high color.

Chara, a water weed, grows luxuriantly in reservoirs in which the temperature ranges between 80.6 to 87.0°F., once they are seeded. *Chara* was not observed in the Brazos Brook Reservoir during the first 10 years it was in service. Then it appeared suddenly, and from that time on the maintenance gang was kept busy removing it especially during the dry seasons when the water level dropped. In 1916, the water in this reservoir was drawn down 10 ft. below the maximum water level, and although the area thus exposed was cleaned very thoroughly and large quantities of *Chara* were removed and burned, a luxuriant growth appeared again within a few months after the reservoir was refilled with water.

About a year later *Chara* appeared in the Agua Clara Reservoir, located about 2 miles from Brazos Brook Reservoir, and likewise was a source of expense and trouble especially in later years when the Health Department found that mosquito larvæ developed in it and threatened to spray the patches with oil to prevent the mosquitoes from emerging.

When the water level dropped in a reservoir in which *Chara* was growing, carpet-like areas appeared at the surface and large numbers of mosquito larvæ developed with the result that great numbers of adult mosquitoes emerged. Enormous amounts of *Chara* are growing over vast areas of Gatun Lake. Just before the rainy season starts, when the water level has dropped enough to expose the *Chara*, flights of *Anopheles albimanus*[37] appear in the Canal Zone towns and army posts, and within a month increased numbers of malaria cases are reported. The distance involved in these flights are much greater than are usually ascribed to the *anopheles*. Gatun Lake comes no nearer than 12 miles to the Pacific Terminal cities and not within 4 miles of the Atlantic side cities.

No satisfactory method of killing *Chara* in Gatun Lake has been developed as yet. The only practical method for controlling it in an arm, from which a water supply is taken, appears to consist in pulling it out of the water. This, of course, is only a temporary remedial measure, and must be repeated frequently. It has been found growing in water 23 ft. deep.

The author believes that *Chara* imparts a musty odor and taste, varying in intensity from 2 to 3 on Whipple's scale, to water in a small reservoir or in an arm of a lake in which it is growing luxuriantly. Dr. D. P. Curry, Assistant Chief Health Officer of the Panama Canal, has identified *Chara sejuncta* and *Chara kenoyeri* (only the male plant).[42, 43, 44, 45] Several species of *Naias* are found in Gatun Lake, and this plant is becoming almost as prevalent as *Chara*.

Rio Grande and Camacho reservoirs were abandoned as sources of water supply after the army posts were removed from the west side of the Canal. Brazos Brook and Agua Clara reservoirs were also abandoned in May, 1926, and January, 1927, respectively. One of the principal reasons for abandoning the two latter reservoirs was to reduce the cost of maintenance which ranged from about $3 600 to $6 000 per year for each one. The raw water supplies for the Mt. Hope and Agua Clara filtration plants were then taken from arms of Gatun Lake. With this change all of the water supplies for the inhabitants of Panama City and Colon, in Panama, and of the Canal Zone communities were taken from Gatun Lake.

Influence of Sea Water on Location of Intake for Water Supply.

While the influence of sea water on the location of an intake for a water supply is not limited to the tropics, the case involving the raw water supply for the Miraflores filtration plant, Canal Zone, is an interesting one.

Miraflores Lake is 1.65 sq. miles in area, with a mean maximum depth of 45 ft. over a large part of it, and covers the entire section between the Pedro Miguel and Miraflores Locks which were constructed to overcome the difference in elevation between the Pacific Ocean and Gatun Lake. The lake is retained by a hydraulic-fill dam, which connects the Miraflores Locks with Cocoli Hill on the west, and a concrete dam, which extends from the locks across the original bed of the Rio Grande River to a hill on the east.

Fresh water enters the lake at the north end from Gatun Lake, through Gaillard Cut, when lockages are made; on the west side from two small rivers; and on the east side from three small rivers. The average elevation of the bottom of the lake at the upper end of the north locks is 15 ft. above mean sea level. The elevation of the upper sill of the locks is 11 ft. above the same datum, and the ship canal in the lake was dredged to this elevation. At maximum water level, the surface of the lake is approximately 55 ft. above sea level.

Salt water from the Pacific Ocean enters the lower or south lock at Miraflores, through a tidal channel, the depth depending upon the height

of the tides which have an average rise and fall of 12.5 ft. and occasionally rise 21 ft.

A ship on making a transit of the Canal from the Pacific to the Atlantic Ocean enters the lower lock, and the gates are closed. Water from Miraflores Lake is then run into the lock until the ship is lifted high enough to pass into the north or upper lock, and the gates are closed. Lake water is again run into the upper lock until the ship is raised to the level of the lake, when the gates are opened and the ship enters it. The result is that with each lockage salt water is carried into Miraflores Lake, the salinity depending upon various factors which it is unnecessary to discuss here.

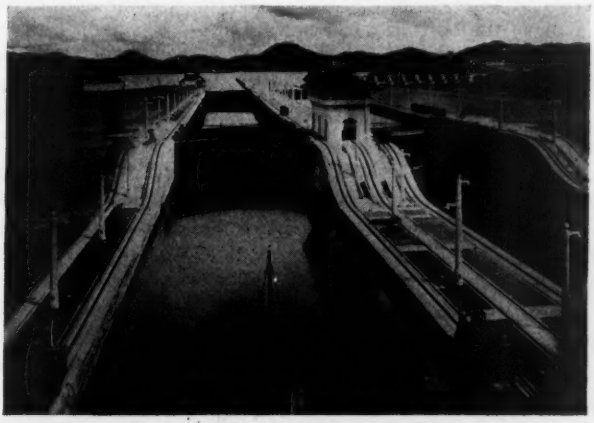

FIG. 20.— MIRAFLORES LAKE AND LOCKS.

Miraflores Locks in foreground; Miraflores Lake in upper center; Pedro Miguel Locks in background against hill; Miraflores filtration plant at upper right. The first pumping station was constructed on arm of lake at extreme right.

It was recognized by the engineer in charge of the permanent water supply project for the Pacific end of the Canal that the chloride content of the lake water, especially in close proximity to the locks, would rise enough to render the water unfit for use. However, it was doubtful whether or not the chloride content of the water in the eastern arm of the lake, the point selected for the raw-water intake, would rise high enough to render it unsuitable for water supply. This arm was cut off from the lake by an embankment, carrying the Panama Railroad, with the exception of two culverts to permit the run-off from the drainage area to enter the lake and to equalize the water level on both sides of the embankment.

In order to use the arm of the lake as a source of water supply, it was necessary to construct an intake chamber for the pumping station before the lake was filled. It was decided to construct these units on the basis

that if the chloride content should rise enough to render the water unfit for use, the expenditure would be lost; while, on the contrary, if the chloride content remained low, a decision to abandon the proposed intake at this time would involve an unnecessary expenditure of nearly $500 000 for a pipe line to Gatun Lake at Gamboa. The distance from this pumping station to the raw-water aëration basin of the filtration plant, to be built on a hill opposite to and on the east side of the upper end of the locks, was only about 1 700 ft.

The Miraflores Locks were placed in operation in November, 1913, and in February, 1914, the chloride content of the water in the lake near the locks had risen from a normal of about 6 p.p.m. to 100 p.p.m. on the bottom and 50 p.p.m. on the surface. In May, 1914, the chloride content had risen to 150 p.p.m. in the bottom water and to 50 to 100 p.p.m. in the surface water throughout the lake. It was then decided to abandon Miraflores Lake as a source of supply and to pump water from the Chagres River at Gamboa, or more properly, from an arm of Gatun Lake at this point, to the filtration plant through a cast-iron pipe line 11.3 miles long.

In May, 1915, near the end of the dry season when the volume of surface run-off entering Miraflores Lake from the drainage area was reduced to a small amount, the chloride content of the samples of water collected at different points in the lake ranged from 1 150 to 1 436 p.p.m. on the bottom and from 636 to 696 p.p.m. on the surface.[38]

As it developed later, the money invested in the pumping station on the arm of Miraflores Lake was not a total loss, as it was converted into an emergency station for service in case of a break in the pipe line from the Gamboa pumping station which could not be repaired in a few hours. The decision to establish an emergency station followed a break in this pipe line by a slide[39] in October, 1923, caused by a series of unusually heavy rains. During about 12 days, it was necessary to pump 8 m.g.d. of water to the filtration plant through 1 600 ft. of pipe line by a 20-in. suction dredge which was set in Miraflores Lake not far from the pumping station which had been built on the eastern arm.

The large volume of surface run-off which entered Miraflores Lake at this time washed out nearly all of the salt water, as the chloride content ranged from 6.9 to 11.9 p.p.m. in the surface samples and from 7.8 to 9.9 in the bottom samples. After the rains ceased, the chloride content increased to about 42 p.p.m. before the Gamboa pipe line was replaced in service. No complaints were received about a salty taste in the filtered water, but when the chloride content reached 40 p.p.m. its effect was noticeable in the boilers of a steam power plant. Within one month after the salt had been washed out of the lake, the chloride content in the surface samples had risen to 202 to 246 p.p.m. and to 246 to 591 p.p.m. in the bottom samples.

Following the rise in the chloride content of Miraflores Lake water, a discussion arose concerning the probability of a similar rise in Gatun Lake and its effect on the water pumped to the Miraflores filtration plant from

the Chagres River arm of the latter lake. The author expressed the opinion that an increase would not occur in the chloride content of the water in this arm of the lake which was approximately 23 miles distant from the Gatun Locks. This opinion was based on the slight probability of an increase in the chloride content of Gatun Lake water at the upper end of the Gatun Locks because of the large storage capacity at this point and the continuous removal by the hydro-electric plant of a relatively large volume of water in addition to that withdrawn for the lockages. Furthermore, during the rainy seasons, an excess of water was discharged into the lake by the Chagres River, and other smaller streams, most of which was wasted through the spillway gates near the Gatun Locks and at the same time removed practically all of any salt water which had accumulated near the latter.

Up to the end of 1934, there had been no increase in the chloride content of the water at the Gamboa pumping station by salt water entering Gatun Lake from the Atlantic Ocean. The chloride content of the raw water entering the Miraflores filtration plant has ranged from 4.5 to 10.5 p.p.m.

Anyone interested in this subject may find additional data in papers [40,41] on the Lake Washington Ship Canal which lies within the city of Seattle, Washington, and connects Puget Sound with the fresh-water harbor comprising Salmon Bay, Lake Union, and Lake Washington. In another interesting case the author found that the water supply for a city would have to be pumped about 24 miles to the filtration plant in order to get beyond the point to which salt water would advance in a ship canal between the Atlantic Ocean and a large river during the low-water stages of the latter.

Scales and Conversion Tables.

In making a contract for the preparation of plans of a water supply system with the Department of Public Works of either a government or a municipality in Spanish America, it is usually specified that the dimensions shall be in the metric system. To designers and draftsmen not accustomed to metric dimensions the author recommends scales of double bevel flat shape graduated in meters on one edge and in feet on the other edge. A set of 1–1000, 1–2000, 1–3000, 1–4000, and 1–5000 scales of this style will simplify the drafting work and save time. As these scales are not carried in stock in the United States, they must be made to order or they may be purchased from the Stanley Company in London, England, either in wood or ivory.

Scales made in a dry climate and transferred to a warm, humid climate will expand so that dimensions scaled off a drawing will be incorrect. Likewise plans made on tracing cloth in a warm humid climate will contract if they are sent to a dry climate, and vice versa.

The author recommends Circular No. 47, "Units of Weight and Measure," published by the U. S. Bureau of Standards, for tables of equivalents from 1 to 999 units.* Another very useful table for the conversion of lengths less than 1 meter may be found on pages 35 to 40 in "Ready Reference Tables," Vol. I, by Carl Hering.† With these tables conversions in length, area, volume, capacity and mass may be made rapidly and accurately.

The author gratefully acknowledges the coöperation of Mr. Theodore Reed Kendall, Engineering Editor, *The American City Magazine*, New York City, in preparing this paper and in presenting it at the Fifty-fourth Annual Convention of this Association.

*This circular may be purchased from the Superintendent of Documents, Government Printing Office. Washington, D. C., for 15 cents per copy.

†John Wiley & Sons, New York.

REFERENCES.

1. The Conquest of New Granada. R. B. Cunninghame Graham. Houghton,Mifflin Co., Boston, Mass.

2. The Seasonal Distribution of Rainfall in South America. Charles Gooze and Clarence F. Jones. Bull. Geographical Society of Philadelphia, **26**: 2, Apr., 1928.

3. The Andes of Southern Peru. Isaiah Bowman. Chapter IX. Henry Holt an Company.

4. Hydrology of the Panama Canal. Caleb Mills Saville. Trans. Am. Soc. Civ. Eng **76**: 871, 1913.

5. The Panama Canal. George W. Goethals. Paper No. 9; The Climatology and Hydrology of the Panama Canal. F. D. Wilson. Vol. I, 222, 1916. McGraw-Hill Book Company.

6. Relation of Seismology to Engineers. R. Z. Kirkpatrick. The Military Engineer, **18**: 97, 12, Jan.-Feb., 1926.

7. Earthquakes in Panama. R. Z. Kirkpatrick. Military Engineer, **23**: 132, 544, Nov.-Dec., 1931.

8. The Managua Earthquake. Dan I. Sultan. Military Engineer, **23**: 130, 354 and 359, Jul.-Aug., 1931.

9. Managua — Its Construction and Utilities. Henry Welles Durham. Eng. News-Record, **106**: 107, 372, Sep.-Oct., 1927.

10. Nicaragua — Its Past and Future. Henry Welles Durham. Military Engineer, **19**: 107, 372, Sep.-Oct., 1927.

11. Rural and Municipal Water Supplies in Haiti. Butler and Choisser. Amer. Jour. Trop. Medicine, **8**: 1, 9, Jan., 1928.

12. Water Supply Problems on the Isthmus. Carleton E. Davis. This JOURNAL, **20**: 3, 252, Sep., 1906.

13. Per Capita Consumption in the Canal Zone and City of Panama. R. C. Hardman. Eng. News-Record, **84**: 23, 1099, June 3, 1920.

14. The Water Supply of Caracas, Venezuela. Thorndike Saville. This JOURNAL, **42**: 303, Sep., 1928.

15. The Panama Canal. Geo. W. Goethals. Paper No. 5; Preliminary Municipal Engineering at Panama. Henry Welles Durham. Vol. I, 117, 1916.

16. The Peninsula of Yucatan. Medical, Meteorological, and Sociological Studies. George Cheever Shattuck. Chapter 11. Carnegie Institution of Washington, Washington, D. C. 1933. Amer. Jour. Trop. Medicine, **10**: 6, 427, Nov., 1930.

17. Health Suggestions for Travelers in the Americas. Bolivar J. Lloyd, Bol. Oficina Sanitaria Panamericana, **13**: 8, 718, Aug., 1934, Washington, D. C.

18. Animal Parasitology. Hegner, Root and Augustine. The Century Co., New York.

19. The Control of Communicable Diseases. Report of a Committee of the American Public Health Assoc. Pub. Health Rep., **50**: 32, 1073, Aug. 9, 1935.

20. Amebiasis and Amebic Dysentery. Charles F. Craig. 1934. Charles C. Thomas, Baltimore, Md.

21. Amebiasis. A Clinical Study. By the late William E. Musgrave. Edited by Alfred C. Reed, Amer. Jour. Trop. Medicine, **11**: 469, 1931.

22. The Incidence and Significance of Infestation with *Endameba histolytica* in New Orleans and the American Tropics. E. C. Faust. Amer. Jour. Trop. Medicine, **11**: 231, May, 1931.

23. A Survey for Amebiasis at Santa Marta, Colombia. Preliminary Report. W. M. James. 14th. Annual Report Medical Dep't, United Fruit Co., 1925, p. 160.

24. A Report on an Investigation of Intestinal Protozoan Infections at Santa Marta, Colombia, in the Hospital of the United Fruit Co., with Special Reference to the Incidence of Amebiasis. Kofoid, Swezy and Boyers. Reference 23, page 140.

25. Reference 16; Chapter 24.

26. 17th. Annual Report Medical Dep't. United Fruit Co., 1928.

27. The Distribution and Complications of Amebic Dysentery Found in 186 Post Mortem Examinations. H. C. Clark. Proc. Internat. Conference on Health Problems in Tropical America, 1924: 315. United Fruit Co., Boston, Mass.

28. Transmission of *Endameba histolytica* in Drinking Water. Robert Hegner, Jour. Parasitology, **20**: 3, 199, Mar., 1934.

29. Incidence of Intestinal Protozoa with Special Reference to the Epidemiology of Amebiasis in the Population of Fresnillo, Zacatecas, Mexico. Justin Andrews. Amer. Jour. Hygiene, **19**: 3, 713, May, 1934.

30. The Epidemiology of Amebiasis. Charles F. Craig. Jour. Amer. Med. Assoc. **103**: 14, 1061, Oct., 6, 1934.

31. The New Water Purification Plant at Miraflores, Canal Zone. George M. Wells. This JOURNAL, **28**: 3, 238, 1914.

32. Pressure Chamber Equalizes Wash-Water Distribution at Miraflores Filters. Geo. C. Bunker. Eng. Record, **72**: 787.

33. New Water Works for a South American City. Geo. C. Bunker. American City, **46**: 5, 75, May, 1932.

34. The covering of Open Service Reservoirs in Which Filtered or Ground Waters Are Stored. Bunker and Nolte. This JOURNAL, **37**: 3, 261, 1923.

35. E. H. Magoon. Bol. San. (El Salvador), **23**, Jan.-Feb., 1934.

36. A Syphon Reservoir Blow-off. Geo. C. Bunker. Municipal Jour. (New York), **46**: 83.

37. Report of the Health Department of the Panama Canal for 1932. Balboa Heights, C. Z.

38. Salt Water Climbs the Locks of the Panama Canal. R. Z. Kirkpatrick. Eng.-News-Record, May 29, 1924, p. 935. How Salt Water Climbs the Miraflores Locks. Geo. M. Wells and R. H. Whitehead. Scientific American, June 2, 1917, p. 551.

39. A Great Flood in the Panama Canal. Jay J. Morrow. Military Engineer, **16**: 86, 100, Mar.-Apr., 1924.

40. The Lake Washington Ship Canal. Arthur W. Sargent. Military Engineer, **19**: 106, 298, Jul.-Aug., 1927.

41. Salinity of the Lake Washington Ship Canal. E. Victor Smith and Thomas G. Thompson. Univ. of Washington Eng. Exp't. Station Bull. 41, May, 1927. Seattle, Washington.

42. Two New Species of *Chara* from Tropical America. Marshall A. Howe. Publications in Botany, Field Museum Natural History, vol. IV, page 159.

43. The British Charophyta, vols. I and II, 1920; Ray Soc. Monograph 102, 1917, by J. Groves and G. R. Bullock. Published by Dulau & Co., Ltd., 2 Stafford St., London, England.

44. Illustrated Flora of the Northern States and Canada, 3 vols. Britton and Brown.

45. Aquatic Plants in Pond Culture. John W. Titcomb. Bureau of Fisheries Document 948, 2nd. Ed. Gov't. Printing Office, Washington, D. C.

Discussion.

Aram H. Hatch.* Mr. Bunker has presented in a comprehensive and commendable manner, the water supply problems of the tropics of Spanish America. The many years of experience of the author in the United States, and more especially in South and Central America, and his intimate knowlegde of the art of water purification in these countries render his paper authoritative and most helpful to readers interested in water supply problems in general.

Mr. Bunker discusses, among other subjects, the water supplies and the water purification plants of the Canal Zone, of which he had charge for approximately thirteen years, from 1914 to 1927, after which time he entered consulting work in water supply.

The writer wishes to make a few supplementary remarks pertaining to the public water supply and water purification plants of the Canal Zone.

The profuse growth of *Spirogyra* and other algæ in the sedimentation basins at the various filtration plants on the Isthmus has been checked in the past few years, by pre-chlorination of the raw water. Other tangible benefits derived from this practice in the water purification plants on the Isthmus have been gratifying, and may be summarized as follows:

(a) Prevention of "feathery" floc formation.

(b) Saving to the extent of 30 per cent. in daily alum consumption.

(c) Considerable decrease in rate of fermentation of sludge in the basins, and consequent delay of rising of sludge.

(d) Lengthening of the period between the washing of sedimentation basins from once a month to once in two to four months, with the following economies:

(1) Preventing the waste of 2½ to 4½ m.g. of water for each month that the washing of settling basins is delayed at the various filtration plants.

(2) Reducing the cost of labor for washing the sedimentation basins and also the wear and tear of equipment used, in connection with this operation, such as pumps.

(e) Rendering the settled water practically sterile, thus decreasing the bacterial load in the filter influent.

(f) Decidedly lengthening filter runs and consequently decreasing the percentage of wash water used at the filter plants.

In the past few years, in addition to post-chlorination, post-ammoniation was instituted at all water purification plants on the Isthmus. The benefits derived from chloramine treatment of the water have also been gratifying by reason of complete elimination of chlorinous taste and odor in the public water supply and also elimination of aftergrowths in the distribution system. In tropical countries, aftergrowths in distribution systems are more pronounced and cause more trouble than in temperate climates.

Mr. Bunker refers to the completion of the Madden Dam on the Isthmus and in this connection makes the statement that, "it will be inter-

*Chief Chemist in charge of Water Purification Plants and Testing Laboratories of the Panama Canal, Ancon, Canal Zone.

esting to observe how the odor and taste of the water supply will be affected by the foul water, which will be discharged from the new impounding reservoir and by the organisms which will develop in it."

In connection with this statement, the writer will briefly discuss the object of constructing Madden Dam and the trouble experienced by impairment of the quality of the public water supply on the Pacific side of the Isthmus when Madden Lake was emptied for the first time, an operation started on March 13, and completed on March 28, 1935.

Lest the writer's discussion in regard to some of the contributing causes, in connection with this trouble, be misconstrued as a criticism he wishes to state that Madden Dam was not constructed as a water works storage reservoir. The construction of Madden Dam was authorized to meet the increasing demand for water for lockage and power, especially during the dry seasons, in connection with the operation of the Panama Canal. By the construction of the dam, a basin was created, where surplus water is stored in the rainy season to be drawn upon during the dry season, to maintain the optimum level of Gatun Lake, from which water is drawn for the following purposes.

(a) Lockage of ships in the locks.
(b) Generation of electric power, at Gatun Hydroelectric Station.
(c) Raw water supply for the various purification plants on the Isthmus.

Another important function of the dam is the creation of a means of control of the Chagres River during heavy floods in the rainy season. These are a possible menace to navigation.

The working level of the dam is at elevation 240 ft. above sea level, and the quantity of water impounded in Madden Lake at this elevation amounts to 22 118 000 000 cubic feet. The total area inundated at El. 240 at Madden Lake is 17.043 sq. mi. Prior to the completion of Madden Dam and its filling,*, the sites of the dam and the saddle dams were cleared and grubbed during the fiscal year 1931 and 1932. The area of the reservoir was also cleared, but stumps and roots were not removed. The total area cleared and grubbed was 2880 acres, 4.5 sq. mi. or 26.4 per cent. of the inundated area at El. 240. Originally, more extensive clearing of the inundated area was planned. This would have been desirable from a public water supply standpoint, but, in 1932, the Board of Consulting Engineers expressed the opinion that the clearing already performed, or contracted for, would be sufficient, and the project of more extensive clearing was abandoned.

All water works engineers will realize that, in the construction of reservoirs for impounding drinking water, it is desirable to remove the top soil in the reservoir area which contains loam, vegetation, and other organic matter, and, also, to clear the land of all timber, including the thorough removal of stumps, in order to avoid serious odor, taste and color trouble in the supply. In the tropics, the complete clearing of reservoir sites and fre-

* Started on September 7, 1934.

quent cleaning of the shore line of reservoirs is very important, on account of the rapid growth of jungle vegetation under the humid and hot climatic conditions prevailing throughout the year. The clearing of the Madden Lake site would have been a stupendous and costly task. On the other hand, for the purpose for which the dam was constructed, this work was not considered important or necessary. It is interesting to note the effects on the public water supply drawn from Madden Lake, even though this reservoir was not constructed primarily as a water works storage reservoir.

From what has been said about the clearing of Madden Lake, it is apparent that the clearing work was not thorough and that this work was done about two years before the lake was filled. Vegetation grows very fast in the Tropics, so that during the period of approximately two years between the clearing work and the filling of the lake, a second growth of vegetation with fresh foliage and light stems had already appeared in the cleared areas. The flooding of this fresh growth, together with that remaining in the areas which had not been cleared, and consequent decomposition of the vegetable matter in the flooded area for a period of six months, under the action of the tropical sun, caused the development of a decidedly objectionable taste and odor in the public water supply on the Pacific side of the Isthmus during March and April, 1935. Long before the spilling of the water through the control works was started, the impounded water in the reservoir had the appearance of a boiling tea kettle, bubbles of gas rose constantly throughout the lake, and the smell of hydrogen sulphide was nauseating at the dam area when the water was allowed to spill over the drum gates. After the draining of the lake, the foul and offensive odor of the aërated water in the aëration basin at the Miraflores filter plant was also very unpleasant and sickening for several weeks. During this period, large quantities of foam virtually covered the surface of water in the aëration basin, mixing chambers, as well as certain parts of the sedimentation basins.

Several days after the spilling of stagnant water was started from the bottom of Madden Lake through the needle valves and sluice gates at Madden Dam, numerous complaints were received from consumers in regard to a peculiar taste in the public water supply on the Pacific side of the Isthmus. The public could not understand this sudden change in the quality of the water, which heretofore had been clear, sparkling and free from odor and taste.

In order to reassure the public in regard to the wholesomeness of the water and also to discredit certain wild rumors which were being circulated on the Isthmus, in connection with this taste and odor, brief articles were given to the press through the Governor's office from time to time. In these articles the reasons for the appearance of taste in the water were explained, by pointing out that this was due to the conditions created by the construction and operation of Madden Dam. At the same time, the public was assured that the public water supply was safe and wholesome from bacterio-

logical and chemical standpoints and that, furthermore, the supply was free from harmful soluble ingredients at all times as heretofore.

Prior to emptying Madden Lake, samples of water were collected periodically, at various depths, for microscopic and chemical analyses. The results of these analyses showed the biological and chemical changes which were taking place in the impounded water. No dissolved oxygen was present at a depth of 50 ft. below the surface, with a total depth of 150 ft. of impounded water at the sampling point.

Following the draining of Madden Lake, decided changes were observed in the chemical characteristics of the incoming raw water at the Miraflores purification plant. These changes in the raw water may be summarized as follows:

(a) Decrease in dissolved oxygen content from an average of 5.80 to 2.80 p.p.m.

(b) Increase in carbon dioxide to a maximum of 13 p.p.m. from an average of 4 p.p.m.

(c) Increase in alkalinity to a maximum value of 85 p.p.m. from an average of 53 p.p.m.

(d) Increase in the organic matter content, as determined by the oxygen-consumed test, to a maximum of 8.2 p.p.m. from an average of 2.2 p.p.m.

(e) Increase in the dissolved iron, and manganese content, due to the solvent action of carbon dioxide on mineral deposits in the Madden Lake area, and in the river bed. The iron and manganese content of the raw water increased from an average of 0.27 p.p.m. of iron and 0.022 p.p.m. of manganese, to a maximum of 0.4 p.p.m. of iron and an average value of 0.095 p.p.m. of manganese.

In addition to the stagnation effects of the lake water which were mainly responsible, at first, for the development of odor and taste in the public water supply on the Pacific side of the Isthmus, another important taste and odor producing factor was that of the vigorous growth of *Peridinium*, about 10 days after draining of the lake, in the intake area of the water supply for the Miraflores plant. The abundant growth of this microorganism was undoubtedly due to an indirect action of stagnation effects of the lake water in providing ample food supply to the organism under the ideal environmental conditions of tropical heat and light. This microorganism appeared very suddenly in vast numbers, so that at one time there were over 1 200 cells of *Peridinium* in one cubic centimeter of raw water, and these multiplied further in the sedimentation basins and even passed through the filters into the clear-water well. The disagreeable fishy and clam-shell odor of this organism was very noticeable at the filter plant, and some drastic action was necessary to get rid of this troublesome organism as soon as possible.

In years past, the elimination of various species of microörganisms in the impounding reservoirs of the Isthmus was successfully accomplished by the use of copper sulphate. However, the application of this reagent in a river was not considered economical or practical. Even if the treatment of the intake area with copper sulphate had been considered advisable, we would not have had sufficient copper sulphate on hand to treat the infected

area. Therefore, it became necessary to resort to some other means to accomplish the same end.

The turbidity of the raw water entering Miraflores purification plant was less than 10 p.p.m. when the concentration of microörganisms was at its height, so that it was not feasible to settle the microörganisms in the sedimentation basins by raising the alum dosage, unless the density of the "floc" could be increased. In order to accomplish this and to settle the microörganisms in an effective manner, arrangements were made at once to add artificial turbidity to the raw water. The artificial turbidity consisted of a good grade of red clay, which was dug from a nearby hill on the premises. After dispersing the clay in water, the mixture was added to the raw water over the weirs leading from the aëration basin and discharging into the collecting box, which is located ahead of the mixing chambers. The continuous addition of artificial turbidity to the raw water to the extent of approximately 40 to 50 p.p.m. proved to be beneficial in producing effective coagulation and sedimentation of the water, as determined by frequent microscopic analysis of the filter influent each day. The results indicated the presence of an average of less than 10 cells of *Peridinium* per cubic centimeter, when the concentration of the same organism in the raw water ranged from 800 to 1 200 per c.c.

In order to determine the distribution and concentration of *Peridinium* in the intake area, as well as further up in the Chagres River, a survey was made by collecting and making microscopic analyses of the river water in a motor boat. The data obtained during this survey indicated that on the day the survey was made, the immediate vicinity of the intake area contained 800 cells of *Peridinium* per cubic centimeter of water,but none of these organisms were detected in the water about one mile east of and above the intake. With the object of replacing the water at the intake area with water impounded in the Chagres River, one mile above the intake, arrangements were made on the same day to spill water at night through the Gatun and Miraflores spillways, and also through the Miraflores Locks culverts. Accordingly, about one billion cubic feet of water were wasted. This reduced considerably the concentration of *Peridinium* found in the intake area on the next day, as shown by a second survey, but it failed to eliminate this protozoön on account of the development of surges in the intake area, produced by the operation of the spillways.

Numerous other measures were adopted in combating the taste and odor in the public water supply by the writer and his assistants, the detailed accounts of which would be too long to include in this discussion. However, the following measures, in addition to those already mentioned, helped to ameliorate the situation.

(a) Increasing the height of sprays at the aëration basin, to obtain a more thorough aëration of water.

(b) Frequent washing of the sedimentation basins.

(c) Decreasing the dosage of pre-chlorination and abandoning, temporarily, the pre-ammoniation of raw water.

(d) Frequent cleaning of the surge tank, from which the raw water flows by gravity to the Miraflores plant.

(e) Decreasing the rate of filtration from 2 to 1½ gal. per min. per sq. ft. of sand area.

(f) Seeding the filter beds with a small amount of activated carbon which was on hand.

(g) Double air and water washing of filters.

(h) Repeated flushing of the mains in the entire distribution system.

(i) Washing the clear-water well and storage reservoirs.

Super-chlorination of raw water prior to aëration was tried but was unfavorable. A shipment of 50 000 lb. of activated carbon, was ordered by radio. It arrived on April 25, 1935, the very day that the plant began to operate normally and the taste and odor trouble in the public water supply disappeared.

Due to certain necessary repairs on the sluiceways of the dam during 1935, it was contemplated to delay the second filling of Madden Lake until September or later, but heavy floods in the Chagres River, during July, 1935, made it necessary to impound the flood waters in Madden Lake, and the repair work had to be abandoned. After July, 1935, additional floods in November filled the lake to overflowing. The lake was lowered to El. 180 immediately after this heavy flood. Beginning in December, the lake was lowered in gradual steps, until on January 24, 1936, the level of the lake stood about at El. 127. This level will be maintained until repairs on the sluiceways are completed.

In order to prevent a repetition of troublesome tastes and odors in the public water supply, dry-feed machines have been installed at all the main purification plants for the application of activated carbon either to water in the mixing chamber or settled water entering the filters. Application of activated carbon at a rate of approximately 1 p.p.m. in the mixing chambers at the Miraflores purification plant was started on December 31, 1935, and has been continued without interruption up to the present time. So far, the concentration of *Peridinium* in the raw water has not exceeded 200 per c.c. Up to the present time, treatment with activated carbon has prevented the development of objectionable taste and odor during the second spilling of the stagnant water from Madden Lake.

The application of activated carbon to the settled water at a rate of 1 p.p.m. was also started about the first part of January, 1936, at the Mt. Hope purification plant. In years past a more or less noticeable taste has been experienced in the output of this plant. Since activated-carbon treatment was started, the palatability of the supply has been improved decidedly, and favorable comments have been received from consumers.

PROCEEDINGS.

NOVEMBER 1935 MEETING.

HOTEL STATLER, BOSTON, MASS.

Thursday, November 21, 1935.

President Roger W. Esty in the Chair.

President Esty announced with regret the death, on November 20, of Fayette F. Forbes, Honorary Member and Past President of the NEW ENGLAND WATER WORKS ASSOCIATION. Mr. Forbes, Superintendent of Water Works, Brookline, Mass., was the oldest living member of the Association and the oldest municipal employee in the United States. He became a member of the Association in 1885 and served the town of Brookline for 61 years.

Secretary Gifford announced the election by the Executive Committee of the following new members: Merritt E. Cutting, Chemist, Metcalf & Eddy, Boston, Mass., and Howard E. Bailey, Assistant Engineer, Metcalf & Eddy, Boston, Mass.

A paper, "Local Control Surveys in Massachusetts as conducted under C.W.A., E.R.A. and W.P.A. in Coöperation with the United States Coast and Geodetic Survey," was read by Elmer C. Houdlette, Administrator and Certifying Officer, E.R.A. Francis H. Kingsbury and President Esty took part in the discussion.

A paper, "New Filter Plant, Mystic, Connecticut," was read by Walter H. Chase, General Manager, Mystic Water Co. Warren J. Scott, T. B. Ray and President Esty took part in the discussion.

A paper, "Protection and Pensions for Water Works Officials and Employees," was read by William W. Brush, Editor, *Water Works Engineering*, New York City. President Esty, William H. Vaughn, Leland G. Carlton, D. A. Heffernan, Secretary Frank J. Gifford, David E. Moulton, E. Sherman Chase, Frank A. McInness and Joseph A. Hoy took part in the discussion.

During the discussion of this paper, the following motion was made by E. Sherman Chase:

> That the President of the Association be authorized to appoint a committee composed of representatives of each of the New England States to determine what steps may be properly taken by the Association to protect competent and worthy municipal water works officials and employees in their tenure of employment and to advise also what measures, if any, should be taken by the Association to further the establishment of pensions for water works employees.

The motion was seconded and, after discussion, unanimously carried.

[*Adjourned.*]

DECEMBER 1935 MEETING.

HOTEL STATLER, BOSTON, MASS.

Thursday, December 19, 1935.

President Roger W. Esty in the chair.

Secretary Gifford announced election by the Executive Committee of the following: Robert Pool Johnson, Chemist, Weston & Sampson, Boston, in charge of Salem and Beverly Water Supply Board Filtration Plant; Charles O. Baird, Jr., East Lynn, Mass., Hydraulic and Sanitary Engineering Department, Northeastern University; Harry H. Smith, Thompsonville, Conn., Superintendent, Water Department, North American Power Company.

An illustrated talk, "What are Algæ and What Do They Look Like?", was given by Professor Melville C. Whipple, Harvard University. This was discussed by Roger W. Esty, F. H. Kingsbury, Warren J. Scott, Caleb M. Saville, Harry M. Clark, David A. Heffernan, and E. Sherman Chase.

A paper, "Frost Penetration as Affected by Weather and Snow Conditions," was read by Harry U. Fuller, Chief Engineer, Portland Water District, Portland, Maine. This paper was discussed by Roger W. Esty, G. E. Lourie, David A. Heffernan, Mr. Bond, Percy A. Shaw, L. A. Goodale, W. A. MacKenzie, L. H. Enslow, B. W. Vaughan, and E. Sherman Chase.

A paper, "New Water Works System for Hinsdale, N. H.," was read by Arthur L. Shaw, Metcalf & Eddy, Boston, Mass. This paper was discussed by Roger W. Esty and L. A. Goodale.

[*Adjourned.*]

JANUARY 1936 MEETING

HOTEL STATLER, BOSTON, MASS.

Thursday, January 16, 1936.

President Roger W. Esty in the chair.

Secretary Gifford announced the election of Edgar Kennard Wilson of Montclair, New Jersey, as a member of the Association.

A paper, "Required Fire Flows, What and Why," was read by P. C. Charnock, Manager, Municipal Protection Department, New England Insurance Exchange, Boston. Francis H. Kingsbury, William A. MacKenzie, and President Esty took part in the discussion.

A talk was given by Selden Allen, Chief of Fire Department, Brookline, Mass., on "Coöperation between Water and Fire Departments." Fire Chiefs Thomas A. Qualey of Medford, George L. Johnson of Waltham, and Frank Dickinson of Brockton, David A. Heffernan, and President Esty, participated in the discussion.

A paper, "Automatic Sprinkler Systems and their Water Supplies," was read by Henry E. Halpin, Engineer, Associated Factory Mutual Fire Insurance Companies, Boston. President Esty, Allen M. Symonds, David A. Heffernan, Francis H. Kingsbury, and Henry T. Gidley took part in the discussion.

[*Adjourned.*]

ROBERT BROOKS MORSE.

ROBERT BROOKS MORSE, Chief Engineer of the Washington Suburban Sanitary District, Hyattsville, Maryland, died Friday, January 31, 1936. Mr. Morse was born September 13, 1880, at Montpelier, Vermont, and was the eldest son of the late Professor Harmon N. Morse of the Johns Hopkins University and Caroline Augusta (Brooks) Morse. He was educated at the Baltimore City College, Johns Hopkins University, A.B., 1901, University of Maine, 1902, and the Massachusetts Institute of Technology, S.B., 1904. He married Caroline E. Ross, in 1902, at Nashua, N. H.

Mr. Morse began his engineering experience as a draftsman in the Bureau of Construction and Repair, Navy Department, Washington, D. C., 1904–1905, after which he was draftsman, assistant engineer, assistant division engineer, Sewerage Commission of Baltimore City, 1905–1910, assistant sanitary engineer, Metropolitan Sewerage Commission of New York, on plans and studies for eliminating the pollution of New York harbor, 1910–1912, chief engineer, Maryland State Department of Health, 1912–1922, in full charge of supervision over water supply and sewerage systems in Maryland, chief engineer, Washington Suburban Sanitary District (an area of 104 square miles in Maryland, adjoining the District of Columbia), in full charge of design, construction and operation of water and sewerage systems, 1918–1936.

Mr. Morse's outstanding achievements were: authorship of the Maryland Water and Sewerage Law in 1914 which has stood the test unchanged for twenty-two years and is still a dominating factor in the control of sanitary conditions within the state; organization and administration of the first engineering bureau of the Maryland State Department of Health and its elevation to a position among the leading states of the country in the betterment of water supply, sewerage and stream pollution conditions; collaboration in the preparation of the Washington Suburban Sanitary District act, drawn with little or no precedent for guidance in creating the pioneer sanitary district in Maryland, which has been used as a model in the forming of similar districts within the state; organization and administration of the engineering work of the Washington Suburban Sanitary District, showing the exercise of the highest degree of originality and skill in the many intricate engineering details involved. In addition he conceived and patented the idea of the concentric steel filter plant assembly recently constructed at Burnt Mills in the Washington Suburban Sanitary District, which has attracted widespread attention throughout the American continent as well as abroad. Also he was the co-holder of patents for efficient methods of pumping sewage and for a special cast-iron cut-in fitting for use in making sewer line connections.

He was a conferee of the New Annex Advisory Commission, Baltimore, 1919, member of the Annapolis Sewerage Commission, 1920, Maryland Park and Planning Commission, 1927, Regional Water Supply, and Drainage and Sewerage Committees of the National Capital Park and Planning Commission, Washington, D. C., 1929–1930, Water Resources Commission of Maryland, 1931–1936, and a member of the sub-committee on the Maryland-Washington Region of the State Planning Commission of Maryland. He had been in private engineering practice since 1910, serving as consulting engineer to the Baltimore City sewer department on sewer system valuation, to Annapolis and Laurel, Maryland, on improvements of the water systems, and to a number of other communities and private enterprises in matters of water supply, sewage disposal and land development. He testified a number of times as an expert witness in matters pertaining to sewerage, sanitation, water supply and power cases.

As a member of the American Water Works Association, Mr. Morse had been chairman of the Publication Committee and a member of the Committee on Water Service Pipes. He represented the American Society of Civil Engineers on the Committee for Standardization of Manhole Frames and Covers, was a member of the Committee on Clay and Cement Sewer Pipe of the American Society for Testing Materials, and a member of the Committee on Municipal Contract Forms of the American Society of Municipal Engineers. He was the author of the section on Metropolitan Water Districts, and co-author of the section on Relation between Filtered Water Storage and Filter Capacity, Manual of American Water Works Practice, as well as author of a number of articles on water and sewerage matters in technical journals. He was a member of the American Society of Civil Engineers, American and New England Water Works Associations, American Society of Municipal Engineers, National Conference on City Planning, American Association of Engineers, Engineers Club of Baltimore, Phi Beta Kappa Fraternity, Manor Club, Beaver Dam Club, and a Fellow of the American Public Health Association.

Mr. Morse's strong character, high principles, keenness of intellect, devotion to his work, helpfulness to those who sought his advice, and his friendly, unassuming manner endeared him to all who knew him and he leaves behind a legion of friends in all walks of life who truly mourn his passing.

His immediate survivors are his widow, Caroline E. Morse, a daughter, Mrs. Julian Ashton Devereux of Ruxton, near Baltimore, a granddaughter, Caroline Vail Devereux, and a sister, Dr. Mary Elizabeth Morse of Baltimore. The burial service was held from his late residence, Luttrell and Franklin Avenues, Hyattsville, on February 3, 1936.

HENRY R. HALL.

1936 CONVENTION

Our fifty-fifth annual convention will be held this year at the Hotel Pennsylvania in New York City from September 22 to 25 inclusive.

A stimulating technical program is being prepared which includes two symposiums—one on the 1936 floods, and the other on water purification—; papers descriptive of the New York City and Dayton, Ohio water supplies; a guest speaker from England; a Superintendents' Session; a Superintendents' Round Table; and other features.

The entertainment committee is making elaborate plans with facilities that only the great city of New York can offer.

Plan now to attend this educational holiday, and meet your colleagues from all over the country.

Table of Contents

PAGE

The New Water Treatment Plant of the Salem and Beverly Water Supply Board. By Frank A. Marston and John W. Raymond 111

Water Department Regulation of Water Pipes Within Buildings. By Stephen H. Taylor 129

Ten Years of Sanitary Improvements in Rhode Island Public Water Supplies. By Charles L. Pool and James J. Dillon 143

Public Ground Water Supplies in Massachusetts. By Francis H. Kingsbury 149

The Water Supply of a State Institution. By Bayard F. Snow 197

Procedure in Developing a Ground Water Supply by Driven Wells. By Ralph W. Horne 207

Determining the Yield and Quality of Tubular Wells by Means of the Well Rater and Sampler. By Paul F. Howard 219

Geologic Features in New England Ground Water Supply. By Kirk Bryan 222

Occurrence of Iron in Ground Water and Early Experiments upon Removal. By Harry W. Clarke 229

Some Problems of Deferrization and Demanaganization. By Robert Spurr Weston 231

Proceedings.

- February Meeting 239
- March Meeting 241
- Spring Meeting, Hartford, Conn. 242
- Spring Meeting, Concord, N. H. 243

Obituaries.

- Xanthus Henry Goodnough 244
- Fayette F. Forbes 247